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الجامعة الأردنيـــة
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التاريــخ: / /

نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

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عنوان الرسالة: Impact of Distributed Generation Location and Capacity on Loss Reduction for Electrical Distribution System.

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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IMPACT OF DISTRIBUTED GENERATION LOCATION AND CAPACITY ON LOSS REDUCTION FOR ELECTRICAL DISTRIBUTION SYSTEM

By

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ii

COMMITTEE DECISION

This Thesis/Dissertation (Impact of Distributed Generation Location and Capacity on Loss Reduction for Electrical Distribution System) was Successfully Defended and Approved on (/ 5 / 2011).

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DEDICATIONS

To my parents and wife for their generous love, extraordinary care and great support. To them I dedicate this work.

I also dedicate my thesis to my brothers, sisters and friends, who always stand beside me in the hardest circumstances in my master study.

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List of Contents

List of Figures

List of Tables

List of Abbreviations

DG	Distributed Generation
LRSF	Loss Reduction Sensitivity Factor
PSO	Particles Swarm Optimization
IDECO	Irbid District Electricity Company
GA	Genetic Algorithm
GAOT	Genetic Algorithm Optimization Toolbox
OPF	Optimal Power Flow
ACO	Ant colony optimization
LLRI	Line Loss Reduction Index
VPII	Voltage Profile Improvement Index
TS	Tabu Search
DPCA	Distributed Power Coalition of America
EPRI	Electric Power Research Institute
CIGRE	International Conference on Large High Voltage Electric Systems
T&D	Transmission and distribution
CHP	Combined heat and power
MTs	Microturbines
FC	Full Cell
DR	Distributed Resources

PV	Photovoltaic
MW	Mega Watt
kW	Kilo Watt
LS	Loss Saving
LRI	Loss Reduction Index
LL_{wDG}	Total Line Losses in the System with DG
LL_{woDG}	Total Line Losses in the System without DG
pbest	Personal Best Position
gbest	Global Best Position

Impact of Distributed Generation Location and Capacity on Loss Reduction for Electrical Distribution System

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ABSTRACT

The function of electrical distribution system is to provide electricity to end user efficiently and with a reasonable assurance of quality. Distribution networks are typically designed and constructed as single radial feeder systems. In distribution systems, the losses are increased in the lines while the voltages are reduced at buses when moved away from the substation. The reason for decrease in voltage and high losses is the insufficient amount of available power, which can be provided by the Distributed Generation (DG).

Distributed Generation is a small generators located at loads near to the end user. It is an efficient solution for reducing losses and improving the voltage in the distribution systems. However, the best locations and sizes of DG have to be considered to maximize the reduction in the total real power loss. With this objective, a proposed algorithm has been applied to identify the optimal locations and sizes of DG whereas the Loss Reduction Sensitivity Factor (LRSF) is used to find the optimal placements of DG and Particles Swarm Optimization (PSO) is used to search for optimum sizes.

The proposed algorithm is tested on IEEE 33 bus distribution system and local network from Irbid District Electricity Company (IDECO). The results show the effectiveness of the proposed algorithm to select the best locations and sizes of DG. Also the results indicate that installing DG in the local distribution networks can provide better results than capacitor banks for the purpose of loss minimization and voltage profile improvement.

CHAPTER ONE

Introduction

1.1 Motivation of the Work

During the last decade, with the introduction of restructuring concepts to traditional power systems and deregulation the electricity market, where competition is introduced in generation, transmission and distribution, a great deal of attention is given to installation of Distributed Generation resources, both from governments and researchers.

Distributed Generation (DG) generally applies to relatively small generating units sited at or near customer sites to meet specific customer needs and/or to support economic operation of the existing power distribution grid. DG can come from a variety of sources and technology located at the point of consumption. It can be applied in the form of renewable sources "Green Energy", such as wind, solar, mini-hydro, photovoltaic systems and biomass or in the form of fuel-based systems, such as, fuel cells and microturbines.

Distributed Generation has several benefits for grids and customers, by integrating DG into the utility's power grid, line upgrades can be postponed, generating a portion of electricity to save peak period to reduce the cost of electricity purchased during the peak hours, sell excess generation back onto the grid, standby power, improving the quality and reliability and minimizing losses.

As open access market principles are applied to electrical power sectors in Jordan, the installation of DG will become more interesting for Jordanian utilities in near future, since they have not started using DG technologies yet. Usually, there is a demand growth around 6-7% per year and the load current drawn from the source would increase. This may lead to an increase in system losses and voltage drop in distribution systems.

Distribution companies work to develop their network to fulfill this demand growth and provide their customers with adequate and reliable electric power. For this reason, there is an incentive for distribution companies to minimize losses to improve the performance of their network and achieve more profits. There are many traditional techniques used to minimize losses such as the design of a new distribution system, feeder reconfiguration, capacitor placement, high voltage distribution system, resizing of an existing conductors.

Power losses have become the most concerned issue in power losses analysis in any power system. In the effort of reducing power losses within distribution system, incorporating of DG has become increasingly important as it affects the electric power systems and more directly the distribution system. Though the DG is considered as a viable solution for the most problems that today's utility are facing. With this regard, installation of DG will help in reducing the total power losses and improving the system voltage profile. However to achieve these objectives, the optimum size and location of DG should be investigated.

Many methods have been proposed to define the optimal locations and sizes of DG that can be connected to distribution networks to minimize the total real power loss and

improve the network performance. As a result, a number of optimization approaches have been adopted by various researchers in handling this problem. While some of these methods are suitable for the problem, some are less effective and having many drawbacks. For ease of reference and understanding, these optimization techniques can be classified into four different major groups. They are the analytical optimization approaches, evolutionary algorithm, swarm intelligence optimizations and conventional optimization methods. These methods are briefly described as follows.

1.2 Analytical Optimization Approaches

This technique can be classified into two main categories: loss sensitivity method and analytical method. These methods are described in the following:

1.2.1 Loss Sensitivity Method

This method is based on the principle of linearization of the original nonlinear loss equation around the initial operating point. The loss sensitivity factor method has been widely used to solve the capacitor allocation problem. Its application in DG allocation is new in the field (Kamel and Kermanshahi, 2009).

The “exact loss” formula is used to calculate real power losses in the system, as given by Equation (1.1) (Elgerd, 1971).

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right]$$

Where ,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j) \qquad (1.1)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

and $Z_{ij} = r_{ij} + jx_{ij}$ are the *ijth* element of $[Z_{bus}] = [Y_{bus}]^{-1}$.

where, P_i and Q_i are net real and reactive power injection in bus 'i' respectively from DG, r_{ij} is the line resistance between bus 'i' and 'j', V_i and δ_i are the voltage and angle at bus 'i' respectively. N is the number of buses in the system.

The sensitivity factor of real power loss with respect to real power injection from DG is given by

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\sum_{i=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \qquad (1.2)$$

The buses are ranked in descending order of the values of their sensitivity factors to form a priority list. The top-ranked buses in the priority list are the first to be selected as alternative locations. The effect of number of buses taken in priority will have effect the optimum solution obtained for some system. For each bus in the priority list, the DG is placed and the size is varied from minimum (0 MW) to a higher value until the minimum system losses is found with the DG size.

1.2.2 Analytical Method for Optimum Size and Location of Distributed Generation

The analytical method is used to find the optimum size and location of DG in the distribution system for minimizing the total real power losses. The size of DG that provide the minimum total power losses can be obtained from differentiate Equation (1.1) with respect to injected power and equate to zero. It results as follows:

$$\frac{\partial P_L}{\partial P_i} = 2\sum_{i=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0 \qquad (1.3)$$

It follows that

$$\alpha_{ii}P_i - \beta_{ii}Q_i + \sum_{\substack{j=1 \\ J \neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0 \qquad (1.4)$$

$$P_i = \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i + \sum_{\substack{j=1 \\ J \neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \qquad (1.5)$$

where, P_i is the real power injection at node i, which is the difference between real power generation (P_{DGi}) and the real power demand (P_{Di}) at node i:

$$P_i = (P_{DGi} - P_{Di}) \qquad (1.6)$$

By combining Equations (1.5) and (1.6) one can get Equation (1.7).

$$P_{DGi} = P_{Di} + \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i + \sum_{\substack{j=1 \\ J \neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \qquad (1.7)$$

Equation (1.7) gives the optimum size of DG for each bus i that gives the minimum losses. Any size of DG other than P_{DGi} placed at bus i, will lead to higher loss. This loss, however, is a function of loss coefficient α and β. When DG is installed in the system, the values of loss coefficients will change, as it depends on the state variable voltage and angle.

1.3 Evolutionary Algorithms

Evolutionary Algorithms are the common term used for algorithms based on principles of nature (evolution, genetic). The Evolutionary Algorithms contain genetic algorithms, evolution strategies, evolutionary programming and genetic programming. The Genetic Algorithm and its combination with other approaches as a Hybrid Genetic Algorithm are enumerated and briefly described in this section.

1.3.1 Genetic Algorithm Approach

Another type of method that is used to solve the optimum location and size problem of DG is GA. GA provides a solution to a problem by working with a population of individuals each representing a possible solution. Each possible solution is termed a "chromosome". New points of the search space are generated through GA operations, known as reproduction, crossover, and mutation. These operations consistently produce fitter offspring through successive generations, which rapidly lead the search toward global optima. The features of GA are different from other search techniques in the following aspects:

1. The algorithm is a multipath that searches many peaks in parallel, hence reducing the possibility of local minimum trapping.

2. Genetic Algorithm works with a bit string encoding instead of the real parameters. The coding of parameter will help the genetic operator to evolve the current state into the next state with minimum computations.

3. Genetic Algorithm evaluates the fitness of each string to guide its search instead of the optimization function. The GA only needs to evaluate objective function (fitness) to guide its search. There is no requirement for the operation of derivatives.

4. Genetic Algorithm explores the search space where the probability of finding improved performance is high.

The main operators of GA used are:

Crossover operator is applied with a certain probability. The parent generations are combined (exchange bits) to form two new generations that inherit solution characteristics from both parents. Crossover, although being the primary search operator, cannot produce information that does not already exist within the population.

Mutation operator is also applied with a small probability. Randomly chosen bits of the offspring genotype flip from 0 to 1 and vice versa to give characteristics that do not exist in the parent population. Generally, mutation is considered as a secondary but not useless operator that gives a nonzero probability to every solution to be considered and evaluated.

Elitism is implemented so that the best solution of every generation is copied to the next so that the possibility of its destruction through a genetic operator is eliminated.

Fitness scaling is referred to a nonlinear transformation of genotype fitness in order to emphasize small differences between near – optimal qualities in a converged population.

1.3.2 Hybrid Genetic Algorithm Approach

Many researchers made a combination of GA and one of other optimization techniques for a better solution. The combination with other techniques such as Optimal Power Flow (OPF), analytical method...etc. is quite efficient in finding the absolute optimum solution and at the same time overcome the robustness in the other search method.

1.4 Swarm Intelligence Optimizations

In this section, two methods in the field of Swarm Intelligence are described; these techniques are Ant Colony and Particles Swarm optimizations.

1.4.1 Ant Colony Optimization

Ants are social insects living in colonies with interesting foraging behavior. In particular, an ant can find shortest paths between food sources and a nest while walking from food sources to the nest and vice versa, ants deposit on the ground a chemical substances called pheromone smelled by other ants to choose path marked by strong pheromone concentration.

Ant Colony Optimization (ACO) algorithm uses a population of ants, otherwise known as colony to collectivity solves the optimization problem under consideration. Each ant searches for optimum solution based on its privet information and the information available in the local node it visits. As a matter of fact, each ant of colony is complex enough to find a feasible solution; nevertheless, a collective interaction among these ants would yield better quality result.

1.4.2 Particle Swarm Optimization

Particles Swarm Optimization (PSO) is an efficient approach for optimization problems. It is developed by Kennedy and Eberhart in 1995 as an alternative to GAs, inspired by social behavior of bird flocking or fish schooling. Like other stochastic searching techniques, the PSO is initialized with generating a population of random solutions, which is called a swarm. Each individual is referred to as a particle and presents a candidate solution to the optimization problem. A particle in PSO, like any living object, has a memory in which retains the best experience, which is gained in the meanwhile of searching solution area (Wong, et al., 2010).

In this technique, each candidate solution is associated with a velocity vector. The velocity vector is constantly adjusted according to the corresponding particle’s experience (this value is called pbest), and according to the experience of a neighboring particle (this value is called gbest). Accordingly, in PSO algorithm, the best experiences of the groups are always shared with all particles and hence, it is expected that the particles move toward better solution areas (Xiaoqun, et. al., 2006), (Niknam, 2006).

Particle Swarm Optimization can be used to solve many of the same kinds of problems as GA. This optimization technique does not suffer, however, from some of GA's difficulties; interaction in the group enhances rather than detracts from progress toward the solution. Further, a particle swarm system has memory, which the GA does not have. Traditionally, PSO has no crossover between individuals and has no mutation, and particles are never substituted by other individuals during the run. Instead, the PSO refines its search by attracting the particles to positions with good solutions. PSO has the following main features compared with the conventional optimization algorithms (Wong, et al., 2010).

- It has very few algorithm parameters, so it can be easily programmed and modified with basic mathematical and logic operations.
- It is very efficient in performing global search and objective function is directly used as fitness function in PSO.
- The PSO has less sensitivity to a good initial solution since it is a population – based method.
- The PSO can be combined with other optimization methods to form hybrid techniques have a better performance.

More features of PSO comparing with the GA approach as following:

- The PSO can be easily programmed and modified with basic mathematical and logic operations.
- It is inexpensive in terms of computation time and memory.
- It needs less parameter tuning.

1.5 Conventional Optimization Methods

- Tabu Search.
- Lagrangian Multipliers.
- Optimal Power Flow.

1.6 Objective of the Work

The main goal of this work is to identify the optimum locations and sizes of DG to be placed in the radial distribution system in order to obtain the maximum loss reduction using an optimization technique combine the PSO and LRSF approaches. A two stage methodology is proposed to solve the problem. In first stage, the candidate locations to place the DG are identified by using LRSF. In the second stage, PSO technique is used to compute the optimum sizes of DG for minimizing the total power losses and improving the voltage profile.

In this work, the proposed algorithm is coded using MATLAB whereas the PSO is adopted for solving the optimum size of DG and the LRSF is employed to solve the optimum locations.

In order to show the capability of the proposed algorithm to solve the problem of the optimal DG allocation and size in the distribution system, a simulation for searching space and the convergence characteristic of the best solution using MATLAB was carried out for two tested distribution systems; classical IEEE 33 bus distribution system and local distribution network supplied by Irbid District Electricity Company (IDECO).

Irbid District Electricity Company applied power loss analysis on the local distribution network using CYME software and the results proposed to install two capacitor banks to reduce the losses and improve the voltage. The proposed algorithm has been applied on the local distribution network, and the results show the effectiveness of the proposed algorithm to minimize the real power losses.

A comparison between the results of IDECO's study and the proposed algorithm indicates that installing the optimum size of DG at candidate locations can provide better results than capacitor banks for the purpose of loss minimization and voltage profile improvement.

1.7 Organization of the Work

The work has been organized in six chapters as follows:

This Chapter One (Introduction) highlights a brief introduction about the work, the motivation of this work and main goal of this work.

Chapter Two (Literature Review) describes the major optimization techniques were employed to solve the optimization problem. A review of previous works carried out by various researchers is introduced in addition to examine the benefits and drawbacks of these techniques.

Chapter Three (Distributed Generation and Problem definition) discusses the general definitions, applications, technologies and development of DG, in addition to define the problem of optimal location and size of DG; and the outline of the work is also given in this chapter.

Chapter Four (Proposed Methodology) briefly describes LRSF and PSO approaches. A proposed methodology is discussed to identify the candidate locations and sizes of DG.

Chapter five (Application of Proposed Algorithm on Experimental Studies) examines how using proposed method to solve the optimization problem. Furthermore, this methodology is worked out on IEEE 33 bus distribution system and local distribution network supplied by IDECO. Also the summary and achieved results are discussed.

Chapter Six (Conclusions and future works) gives conclusions and scope of future work in the field of optimal placement and sitting of DG in the distribution system.

CHAPTER TWO

Literature Review

In recent years, various methodologies have been applied in the field of determining the optimal size and location of DGs in the distribution system. In this chapter, a review of various methodologies proposed by the researches is presented. These methodologies can be categorized into two main optimum searching solutions; local optima and global optima.

2.1 Local Optima Solutions

Griffin, et al. (2000) proposed loss sensitivity method whereas the sensitivity factors are calculated for each bus to form a priority list. The top-ranked buses in the priority list are the first to be studied alternative locations. The advantage of this method that it will reduce the solution space to few buses, which constitute the top ranked buses in the priority list, while the main disadvantages of this method are:

- This process finds the local optimum solution not a global solution for the distribution system, because of using single DG placement algorithm.
- The process is inefficient due to a large number of load flow computations, and this may not determine exactly the size and location of the DG, as varying the size of the DG will be in steps.

Naresh, et al. (2006) proposed an analytical method to find the optimal size and to identify the optimum location of DG in the distribution system for minimizing the total real power losses. The optimum DG location obtained by calculating approximate loss using Equation (1.1) for each bus after placing the optimum size of DG for that bus. In this method (Naresh et al., 2006) improved the method of (Griffin, et al., 2000). The main feature of this method compared with loss sensitivity method as described previously, that one can avoid exhaustive computation and save time. The load flow is carried out only two times, one for the base case and another at the end with DG included to obtain the final solution. The drawbacks on this method are:

- This method requires exhaustive search for all possible locations which may not be applicable to more than one DG, so this method has the same demerit as loss sensitivity factor method.

- After installing the DG, the values of the voltages and angles at all buses have a significant changes and this may lead to a high error in the optimal size obtained by Equation (1.7).

- Using Newton–Raphson algorithm to solve the load flow problem is not valid in distribution systems. It is well known that in the distribution network the ratio of R/X (resistance/reactance) is relatively big, even bigger than 1.0 for some transmission lines. In this case, P - Q decoupled load flow is invalid for distribution network load flow calculation. It will also be complicated and time – consuming to use the Newton – Raphson load flow because the distribution network is only a simple radial tree structure (Zhu, 2009).

Kazemi and Sadeghi (2009) used the analytical method to find the proper location of a DG unit in order to improve the voltage profile of the system in addition to decrease the power losses. The proper place is determined by establishing a compromise between the decreasing the power losses and improving the voltage profile of the entire system, so the algorithm consists of two sections. At the first step, sensitive buses to voltage (buses with low voltage magnitudes) are considered and ranked. In the second step the losses in each bus after DG installation is considered and it can be ranked from the minimum loss to the maximum one. Then the best location to have a good voltage control and minimum loss can be found. This method is suitable for the local optimum solution not a global one, in addition, it is required large number of processes to solve the problem.

Mithulananthan, et al. (2004) used the Genetic Algorithm Optimization Toolbox (GAOT) to obtain the optimal size and location of DG for minimizing the total real power losses in the distribution system. The study results shows that the proper placement and size can reduce the percentage of losses up to 80%. The GAOT has reached the optimum solution with 100 iterations. Despite all of these, this method has the following disadvantages:

- This type of algorithm is actually unconstrained optimization, so all information must be expressed in a fitness function and one has to neglects the network losses and network constraints to use GA easily. However, in practice there will be many constraints should be considered to find the optimum size and location of DG which limit the efficiency of using this method.

- The principle problem in using GA rests on an efficient coding and decoding mechanism of the chromosome representing the distribution network and the structure of fitness function.

- The GA is suitable for multi-objective problems like find global solution of DG allocation, but in this method the author being trapped in local optima.

2.2 Global Optima Solutions

Haesen, et al. (2005) proposed a GA to search for the optimal placement of the different types of DG in such a way that the power losses are minimized while the voltage profile within an acceptable level, the proposed method is considered a non-convex optimization problem that requires exhaustive search. This methodology based on GA is suitable for multi-objective problems and can give near global optimal results.

Sedighizadeh and Rezazadeh (2008) presented a method for the optimal allocation of DG in the distribution systems for voltage profile improvement and loss reduction. The application of this method has the following demerits:

- The appropriate selection of the first population is effected on algorithm convergence. So the correctness of grid coding and fitness values shall be considered.

- While placing of DG in network with lower number of buses, disabling the GA operators, cause to convert GA to direct search. Absolute optimal point is given by this way and in case of increasing the number of buses, even with one DG resource, direct research finished by increasing of calculating and passing time.

- Considering the load flow algorithm, one disadvantage of GA in this routine is increasing of computing level and passing time.

- If the amounts of chromosomes which enter in matting pool are low, the optimal solution will not be accurate and has a point near the absolute solution.

Pisică, et al. (2009) proposed a comparison between nonlinear optimization and GA for optimal location and sizing of DG in the distribution network. The study shows the importance of installing the right amount of DG in the best suited location. The result shows that the nonlinear optimization algorithm cannot face the high complexity problem of allocating more than two DG units, in comparison with GAs. Even though the losses in the case of GA for one DG unit are slightly higher than the losses resulted with the nonlinear optimization algorithm, the superiority of GA is proven when the problem complexity increases and the nonlinear optimization algorithm fails to provide a solution.

Kim, et al. (2002) used a combination of fuzzy non-linear goal programming and GA techniques to locate DGs and minimize overall power losses. The main idea of solving fuzzy non-linear goal programming is to transform the original objective function and constraints into the equivalent multi-objective function with fuzzy sets to evaluate their imprecise nature. The problem is solved with GA without the need to transform the non-linear problem into a linear model. This approach is good for solving constrained multi-objective problems.

Siano, et al. (2007), Harrison, et al. (2007) proposed a hybrid method employing GA and Optimal Power Flow (OPF) aims to identify the best sites and capacities available to strategically connect a definite number of DGs among a large number of potential

combinations. The OPF computes the fitness function of GA that is fed back to the GA to search for the optimal capacity of DG.

Falaghi and Haghifam (2007) presented ACO approach based on a cost model to find the optimal size and location of DG. In this method the DG units was considered as constant power source in minimizing the objective function of DG investment cost and the total operation cost of the system in determining the optimal number and location of DGs in distribution system.

Krueasuk and Ongsakul (2006) applied the PSO algorithm on three different types of DG to determine the optimal sizes and location of DG. A comparison of PSO method with analytical approach method has been done. The results of tested IEEE 33-bus and 69-bus radial distribution systems indicate that PSO method can obtain better results than the analytical approach method. The drawback on this method that it is computationally inexpensive in terms of memory and speed, since the Newton–Raphson algorithm was used to solve the load flow problem.

Wong, et al. (2010) combined the PSO and the Newton-Raphson load flow method to find the optimum location and size of the DG to minimize the total power losses of the system in a single step. The DGs that produce real power only has considered. The results of the tested IEEE 69-bus radial distribution systems show that the installation of DG to the system reduces the total line power losses and improves the voltage profile. The drawbacks on this method are using Newton–Raphson algorithm to solve the load flow problem and being trapped on local optima.

Raj, et al. (2008) employed the Line Loss Reduction Index (LLRI) and Voltage Profile Improvement Index (VPII) to evaluate and quantify the benefit of installing DG in the distribution system. For this purpose, the PSO is used to find out the optimal value of the DG capacity to be connected to the system. A combined objective function was designed to reduce power loss and also improve system performance for various values of DGs.

Xiaoqun, et al. (2006) applied a Scenario Probability methodology combining with PSO to take DG optimal planning. The methodology separates random DG output into several portions. Every portion is related to different DG output scenario. Three scenarios has been considered: Scenario I where the DG output is equal to rated power; Scenario II where the DG output is 75% of rated power; and Scenario III where the DG output is 50% of rated power. The probability of each scenario is 0.48, 0.39 and 0.13, respectively. Planning methods consider investment cost and power loss of distribution network. Technical constraints such as capacity power limits, voltage profile are considered. The size and complexity of the algorithm need large number of computations. The results of this method are not guaranteed to be optimal.

Maciel and Padilha (2009), Nara et al. (2001) proposed multi-objective optimization technique using TS. The method is highly successful in finding near optimal solutions and has the ability to avoid entrapment in local optima by using flexible memory system. However, this method does not produce accurate result, so the results are not guarantee to be optimal. In addition it’s computationally in terms of memory and speed is low class.

Rosehart and Nowicki (2002), Gautam and Mithulananthan (2007) proposed to use Lagrangian multiplier in which the objective function is subjected to certain non-linear system constraints. This approach is easy to solve and can handle more constraints but it is not sufficient optimality if the order of dimensionally of power systems is increased.

Harrison and Wallace (2005) employed optimal power flow OPF for the capacity evaluation. The presented method used technique of modeling steady-state DGs as negative loads, while the conditions for voltage and thermal violation are of primary concern. The objective function is to maximize the capacity of DG. The capacity maximization is adapted from an OPF formulation designed to minimize the cost of load. This method has capability for optimizing complex problems with many variables, but when the function is highly complex it would be hardly to find global optimum solution and the solution easily trapped in local optima and the result may not be optimal.

CHAPTER THREE

Distributed Generation and Problem Definition

3.1 Distributed Generation Development

Distributed Generation is not a new concept but it is any small-scale electrical power source that is connected directly to the distribution system close to the customer’s facilities. According to the Distributed Power Coalition of America (DPCA), research indicates that distributed power has the potential to capture up to 20% of all new generating capacity, over the next two decades (Borbely and Kreider, 2001). A research study made by the Electric Power Research Institute (EPRI) has indicated that about 25% of the new future electrical power generation will be DG, while a study by the Natural Gas Foundation concluded that this Figure would be nearly 30%. The European Renewable Energy Study found that around 60% of the renewable energy will be decentralized generation due to the feasibility of EU CO^2 reduction goals and the EU renewable energy targets (Ackermann, et al., 2001).

The National Energy Strategy in Jordan calls for renewable energy to account for 7% of the Jordan Kingdom's energy mix within the next five years, and 10% by the end of the decade. Energy officials are planning various projects to produce 1,000 MW of wind power and 600 MW of solar energy to meet the strategic target. (By Taylor Luck, Jordan Times 24 August 2010).

3.2 Distributed Generation Definitions

Due to the large variations in the definitions used in the literature, the general definition for DG is an electric power generation installed directly to the distribution network or connected to the network on the customer site of the meter to provide a source of active electric power (Ackermann, et al., 2001).

Distributed Generation includes all use of small electric power generators, whether located on the utility system, at the site of a utility customer, or at an isolated site not connected to the power grid. The term of dispersed generation is a subset of DG, refers to generation that is located at customer facilities or off the utility system. Usually, dispersed generation is also understood to include only very small generation units, of the size needed to serve individual households or small businesses, in the capacity range of 10 to 250 kW (Willis and Scott, 2000).

With regard to the rated capacity of DG varies terms due to different regulations are used, for example (Willis and Scott, 2000): The Electric Power Research Institute (EPRI) defines DG as generation from a few kilowatts up to 50 MW. According to the Gas Research Institute, DG is typically up to 25 MW. DG can be defined also according to the rated size as ‘ranging from a few kilowatts to over 100 MW (Ackermann, et al., 2001). The International Conference on Large High Voltage Electric Systems (CIGRE) defines DG as smaller than 50 to 100 MW. The DG can be categorized depending on the rating of the generation source; as follows (Pepermans, et al., 2005):

- Micro DG: up to 5 kW.
- Small DG: 5 kW to 5 MW.
- Medium DG: 5 MW to 50 MW.
- Large DG: 50 MW to 300 MW.

3.3 Distributed Generation versus Central Station Generation

Most of the electrical power is derived from large central station plants due to the "economy of scale". Fossil-fuel or nuclear plants have comprised the majority of this power generation. The power generation stations are often large and their capacities are in the range of 150-1000 MW. The main power stations need high capital cost in addition to the large facilities, including land and operators, consequently, these large power stations cannot be constructed closer to load centers, therefore need for long transmission and distribution (T&D) lines.

At present the (T&D) system needs a lot of money for design, construction, operation and maintenance costs around 150% of generation costs. In addition the (T&D) lines are susceptible to failures because of natural hazards such as heavy wind, snowstorms and lightning. These natural hazards cause some line outages, and become the major reason for partial or full black out of the power system; furthermore, the (T&D) losses constitute a major portion of system losses. Distribution losses are the most important because of the close proximity of these networks to the ultimate consumers and of their great length, which has as a consequence increased capital investment and increased operational costs because of their losses.

This is typically done because in the past, the cost of producing bulk quantities of electricity is generally much less than the cost of producing smaller quantities of electricity. On the other hand and due to the increasing in electricity costs and growing interest toward environmentally friendly energy sources, the incorporation of smaller scale generation such DG in the electrical power systems is becoming more popular.

3.4 Distributed Generation Applications

Distributed Generation can provide many benefits for both utilities and consumers, including standby power, peak shaving capability, grid support, base load generation, or combined heat and power that provide thermal and electrical loads of a given site. These applications are discussed below:

Standby power: Where the DG is used for customers that cannot tolerate interruption of service for either public health and safety reasons, or where outage costs are unacceptably high.

Stand-alone: DG is used in remote areas to provide customer with electricity but is not connected to the grid, either by choice or necessary where the cost of connecting to the grid very expensive. Such applications include users that require stringent control of the quality of their electric power, such as computer chip manufacturers.

Peak load shaving: The electric power cost varies according to the load demand curves and the corresponding available generation at the same time. Using DG during relatively high-cost on-peak periods is called peak shaving. Peak shaving benefits the energy supplier as well, when energy costs approach energy prices, however, large

industrial customers can benefit by saving on their electricity bill by self-generation during high-cost peak power periods.

Combined heat and power (CHP): DG can provide CHP as a cogeneration has a high overall energy utilization efficiency. Applications make use of the heat from the process of generating electricity to increase the efficiency of the used fuel. That heat can also be used for industrial processes, heating or air conditioning. CHP is used for a wide range of applications in hospitals, large commercial areas and process industries.

Base load: Utilities are usually use DGs as a base load to provide part of the main required power and support the grid by enhancing the system voltage profile, reducing the power losses and improving the system power quality.

3.5 Distributed Generation Technologies

Most types of distributed generators utilize traditional power generation such as microturbine and nontraditional generation such as fuel cells and renewable power generation such as wind and photovoltaic energy. Some of DGs technologies are discussed below:

3.5.1 Microturbines

Microturbines (MTs) operate on the same principles as traditional gas turbines. Air is drawn into the compressor where it is pressurized and forced into the cold side of the recuperator. Here, exhaust heat is used to preheat the air before it enters the combustion chamber. The combustion chamber then mixes the heated air with fuel and burns it.

Microturbines are available in power ratings range from 20 – 750 kW although multiple units may be directly interconnected to provide up to 10 MW. They have electrical efficiency range from 27-32%. Utilizing the exhaust heat can improve the overall efficiency up to 80%. Typically, MTs use natural gas as fuel, but other fuels such as diesel, propane, kerosene and fuel oil are possible.

Microturbines may offer one of the best short-term distributed power production options because of their simplicity and because no major technological breakthroughs are required for their deployment. MTs have the following characteristics in their market (Khattam and Salama, 2004):

1. Durability and low maintenance.
2. They have well-known technology, simple design with a high potential for inexpensive and high-volume manufacturing.
3. Compact in size and light in weight and can be installed on-site and they can start-up easily.
4. They have lower operation costs and lower capital costs compared to other DG types.

3.5.2 Reciprocating Engines

Use of diesel and petrol engines to provide standby power for commercial and small industrial customers is not new. Recently engines operating on natural gas have been developed such as MTs. Typical efficiencies range from 33-36% and capacities range from 50 kW to 5 MW. Disadvantages of combustion engines are pollution (both emissions and noise) and relatively high maintenance and operation costs. Reciprocating engines are

currently a promising technology for DG systems up to 5 MW (Borbely and Kreider, 2001).

3.5.3 Fuel Cells

A Fuel Cell (FC) is an electrochemical device that generates electricity by combining hydrogen from a hydrogen-rich fuel (methane, methanol, propane, or biomass) with oxygen from the air to produce electricity, heat, and water. All fuel cells consist of anode, cathode and electrolyte; much like a battery, except that the reactant fuel is continuously fed to the cell and fuel cells electrochemically convert the energy in a hydrogen-rich fuel directly into electricity.

Fuel Cell efficiency can range between 35-65%. Utilizing the produced heat can raise the efficiency to over 80%. Fuel cells are typically aimed at single installation sites (i.e., one bank of fuel cells) that require between 50 and 1000 kW, e.g., high rise office buildings, hospitals, schools, hotels, restaurants, etc. Where environmental regulations are strict, fuel cells offer the only truly clean solution to electricity production outside of the renewable solutions (El-Khattam and Salama, 2004).

3.5.4 Renewable Resource Distributed Generation

Distributed Generation can include renewable power generation resources such as wind, solar, and photovoltaic, some researchers and institute use the term of Distributed Resources (DR) to define this kind of energy. These technologies are still cost electricity price higher than that of power generated from conventional oil sources. The most popular types of renewable resources are discussed below:

3.5.4.1 Solar Thermal Power Generation

Among all the possible renewable energy sources, the most flexible and applicable in many respects is solar power.

Solar Thermal Power Generation: Light → Heat → Power

One of the most popular methods for converting concentrated solar power into electric energy is solar thermal steam generation, in which heat from concentrated sunlight is used to produce steam to drive a traditional steam-generator. The net solar to electrical efficiency of a solar thermal power plant is roughly 12% (Willis and Scott, 2000).

3.5.4.2 Photovoltaic

Photovoltaic (PV) directly convert sunlight into electricity through the use of photovoltaic cells, which are grouped together to form a panel. Photovoltaic panels can be used in small groups on rooftops or as part of a substantial system for producing large amounts of electrical power. The amount of energy produced by a photovoltaic system depends upon the amount of sunlight available. The intensity of sunlight varies by season of the year, time of day, and the degree of cloudiness. Currently, photovoltaic generated power is less expensive than conventional power where the load is small or the area is too difficult to serve by electric utilities. Today, there is a PV market worldwide of the order of 100 MW per year. A key advantage of PV systems is that they can be constructed as either grid connected or stand-alone to produce outputs from microwatts to megawatts (Borbely and Kreider, 2001). PV technology offers the highest efficiency in terms of percentage of sunlight converted to electric power. Efficiencies exceeding 25-28% are quite feasible, although perhaps not economical (Willis and Scott, 2000).

3.5.4.3 Wind Energy

Wind energy is converted to electricity when wind passes by blades designed like those of an airplane propeller mounted on a rotating shaft. As the wind moves the blades, the rotation of the shaft turns a generator that produces electricity. This is done using some form of windmill (wind turbine), or any of several other types of devices that are essentially similar in operating concept.

Three factors affect wind machine power: the length and design of the blades, the density of the air, and wind velocity. Blades are shaped and positioned to take advantage of different wind velocities so that, depending on design, one wind machine may produce power in a different range of wind velocities than another.

Typical systems range from 30 kW for individual units to 1.5 MW for wind farms of multiple units. Windmills are often installed in groups, or wind farms, and are seldom used in isolation. The electrical efficiency is around 25%.

3.6 Distributed Generation Benefits

Distributed Generation has several benefits for grids and customers, by integrating DG into the utility's power grid, line upgrades can be postponed, generating a portion of electricity to save peak period to reduce the cost of electricity purchased during the peak hours, sell excess generation back onto the grid, standby power, improving the quality and reliability and minimizing losses.

The Working Group 37.23 of CIGRE (1999) has summarized the impact reasons of increasing contribution of DG in different countries. The current trend for interesting in DG among the utilities around the world is basically due to combination of five major factors:

deregulated electricity market, development in DG technology, constraints on the construction of new transmission and distribution lines, reliability improvement and concerns about change in the world's climate. It can be found in several publications that DG can provide benefits to the network, which can be classified into three major categories; economical, technical and environmental advantages, which are as follows:

3.6.1 Main technical benefits:

- Minimizing losses for (T&D) networks.
- Peak load shaving.
- Improving voltage profile and load factors.
- Increasing overall energy efficiency.
- Improving continuity and reliability.
- Improving power quality.
- Relieving thermal constraints of (T&D) feeders.

3.6.2 Main economic benefits:

- Deferring new (T&D) upgrades for some years.
- Land requirement for power plant construction and resettlement.
- Reducing operation and maintenance costs of some DG technologies.
- Reducing fuel costs due to increased overall efficiency.
- Lower operating costs due to peak shaving and sufficient supply availability.
- Increasing security for critical loads.
- Stimulating competition, and reducing wholesale electricity price.

3.6.3 Main environmental benefits:

- Reduction of emission pollutants.
- Low noise.
- Energy saving.

3.7 Optimal Placement and Size of Distributed Generation

Placement of DGs is an interesting research area due to economical reason. DG technologies (such as fuel cells, combustion engines, microturbines, etc.) can reduce the system loss and defer investment on transmission and distribution expansion.

The problem of DG unit placement consists of determining the locations and sizes of DG units to be installed in the distribution system such that maximum benefits are achieved while operational constraints at different loading levels are satisfied. The placement and size of the DG are two crucial factors in loss reduction. Studies have indicated that inappropriate selection of the location and size of DG may lead to greater system losses than losses without DG, which implying in an increase in costs and, therefore, having an effect opposite to the desired, but by selection the optimum allocation and capacity, utilities will take advantage of a maximum reduction in their losses, furthermore, an improvement in the voltage regulation and the reliability of supply.

If the size of DG is further increased, the losses starts to increase and it is may reach value of losses above the value in the base case. Also notice that location of DG plays an important role in minimizing the losses. The total capacity of installed DG should be consumed in the distribution system to prevent reverse flow of power though the distribution systems, and then lead to increase in the losses. So, the size of distribution

system in term of load (MW) will play important role in selecting the size of DG. Proper placement will also add free available capacity for transmission of power and reduce equipment stress.

Numerous papers have been published on this subject, referring to either "optimal capacity allocation", "DG placement" or even "capacity evaluation". Although the literature suggests a wide variety of objectives and constraints, two main approaches emerge: finding optimal locations for a defined DG capacity and finding optimal capacity at defined locations. Of all benefits and objectives of DG implementation, the idea of implementing DG for loss reduction needs special attention.

Acharya, et al. (2006) provided a 3D plot of typical power losses versus size of DG at each bus in a distribution system as shown in Figure (3.1). The Figure shows that while increasing the size of DG at specified location, the losses are reduced until reach the minimum value at optimum size of DG. When the size of DG is increased above the optimum value, the losses starts increased gradually to be higher than the losses in the base case. In addition the Figure illustrates how the location of DG plays an important role in minimizing the losses in distribution systems.

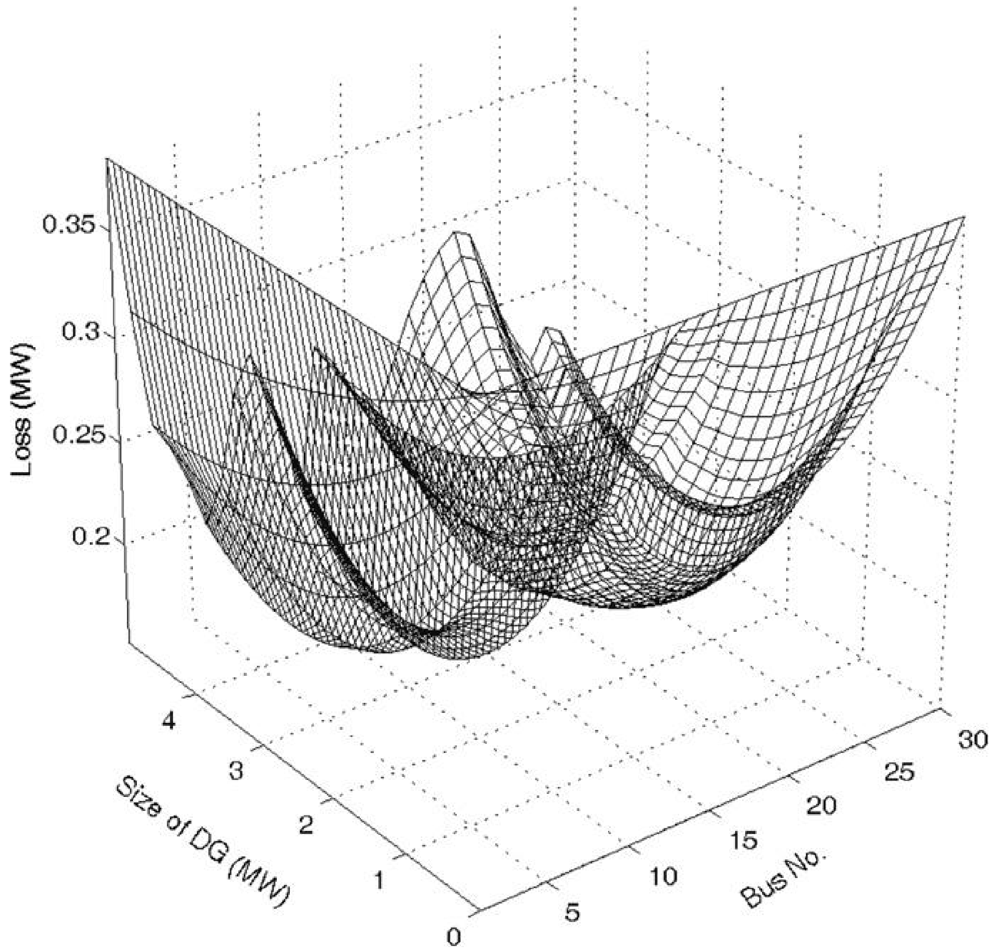

Figure 3.1: Effect of size and location of DG on system loss (Acharya, et al., 2006)

Pisică, et al. (2009) performed a number of load flow simulations on the IEEE 69-bus distribution test system. The results show that the proper placement and size of DG units can have a significant impact on system loss reduction. Figure (3.2) shows the impact of installing different sizes of DG in a particular place. The total system losses have reduced while increasing the size of DG, starting from 500 kW until achieving the minimum losses at optimal size of DG with 1850 kW. Further increasing in the size of DG will lead to increase the losses, and it is may overshoot the losses of the base case.

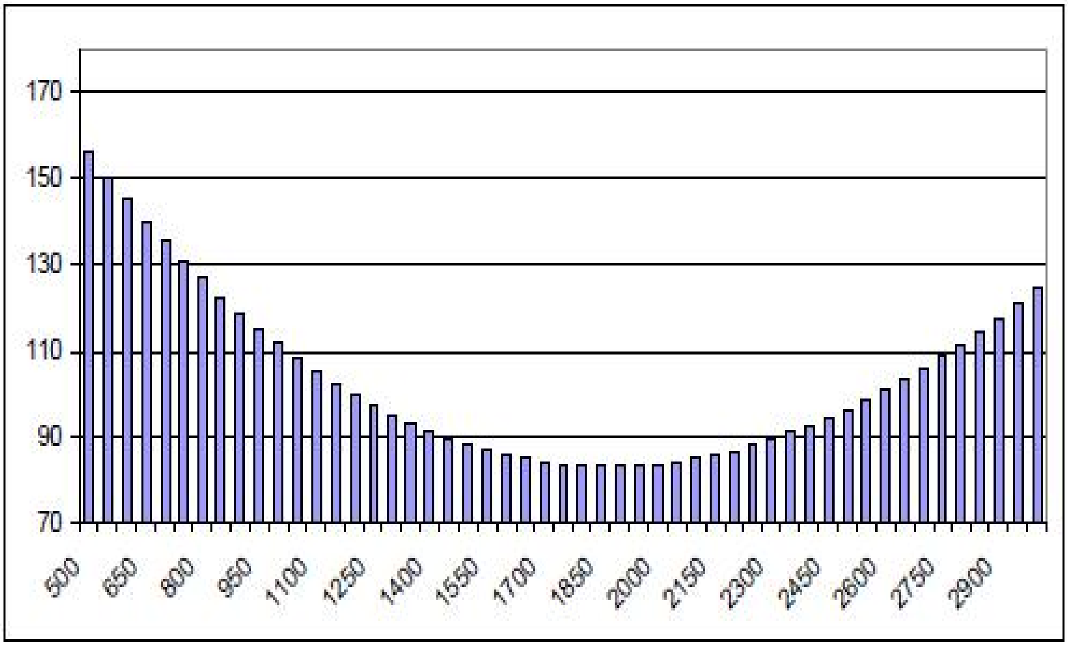

Figure 3.2: The impact of installing different sizes of DG in a particular place (Pisică, et al., 2009)

In electric power systems, most of the electrical energy losses occur in the distribution systems. For this reason, there is an incentive for Distribution Companies to minimize losses to achieve more profits. There are many traditional techniques used to minimize losses such as the design of a new distribution system, feeder reconfiguration, capacitor placement, high voltage distribution system, resizing of an existing conductors.

The integration of DG in the existing distribution system to reduce the total system losses is a new technology and sometimes provides the most economical solution for utilities. Some of distribution companies in Jordan are losing around 15-20% of their total energy as losses while this Figure for a well-developed power system is well under 10%, for that matter installing DG could be an interesting for distribution companies in Jordan; hence they do not have any DG projects underway.

CHAPTER FOUR

Proposed Methodology

A two stage methodology is applied here. In the first stage the optimum locations of the DGs are determined by using LRSF approach and in the second stage a PSO technique has been used for determining the sizes of DGs for maximum real loss reduction. The proposed method is coded using MATLAB to solve the problem of optimum location and size of DG.

4.1 Loss Analysis in Radial Distribution System

The distribution networks are the most extensive part of the electrical power system. They produce a large number of power losses because of the low voltage level of the distribution system. The goal of installing DG in the radial distribution network is to minimizes the power losses and improve the voltage profile of the distribution system under the normal operation conditions.

Power losses in distribution systems vary with numerous factors depending on the system configuration such as level of losses through transmission and distribution lines, transformers, capacitors, insulators, etc. Power losses can be divided into two categories: real power loss and reactive power loss. The resistance of lines causes the real power loss, while reactive power loss is produced due to the reactive elements. Normally, the real power loss draws more attention for the utilities, as it reduces the efficiency of transmitting energy to customers.

The total power loss (P_L) in a distribution system having n number of branches is given by:

$$P_L = \sum_{i=1}^{n} I_i^{\,2} R_i \tag{4.1}$$

where, I_i is the magnitude of the branch current and R_i is the resistance of the i^{th} branch. I_i can be obtained from load flow study. The branch current has two components: active (I_a) and reactive (I_r). The loss associated with the active and reactive components of branch currents are given by:

$$P_{La} = \sum_{i=1}^{n} I_{ai}^{\,2} R_i \tag{4.2}$$

$$P_{Lr} = \sum_{i=1}^{n} I_{ri}^{\,2} R_i \tag{4.3}$$

4.2 Loss Reduction Sensitivity Factor Approach

The Loss Reduction Sensitivity Factor (LRSF) and the criterion to form the priority list to select the candidate locations for losses compensation are described in this section.

4.2.1 Losses Compensation with Distributed Generation

Assume that a single source radial distribution system with '*n*' branches. Let a DG is to be placed at bus '*m*' and 'β' be a set of branches connected between the source and DG unit buses (bus *m*). The DG unit supplies active current I_{DG}, and for a radial network it changes only the active component of current of branch set 'β'. The current of other

branches is not affected by the DG unit. Thus the new active component of current I_{ai} *(new)* of the i^{th} branch is given by (Devi and Subramanyam, 2007), (Lalitha et al., 2010):

$$I_{ai}(new) = I_{ai} + D_i \times I_{DG} \tag{4.4}$$

$D_i = 1$ if branch $i \in \beta$

$D_i = 0$, otherwise

The loss $P_{La}(DG)$ associated with the active loss component of branch currents in the compensated system when the DG is given by:

$$P_{La}(DG) = \sum_{i=1}^{n} (I_{ai} + D_i I_{DG})^2 R_i \tag{4.5}$$

4.2.2 Loss Reduction Sensitivity Factor

The loss saving *LS* is the difference between Equations (4.2) and (4.5) and is given by:

$$LS = P_{La} - P_{La}(DG) = -\sum_{i=1}^{n} (2D_i I_{ai} I_{DG} + D_i^2 I^2{}_{DG}) R_i \tag{4.6}$$

The positive sign of *LS* indicates that system loss is reduced with the integration of DG but the negative sign implies that DG causes higher loss in the system. The sizes of DG that provide the minimum total power losses can be obtained from differentiate Equation (4.6) with respect to injected current from DG. It results as follows:

$$LRSF_i = \frac{\partial LS}{\partial I_{DG}} = -2\sum_{i=1}^{n} (D_i I_{ai} + D_i^2 I_{DG}) R_i \tag{4.7}$$

where, $LRSF_i$ is the loss reduction sensitivity factor of real power loss saving with respect to current injection from DG. Thus the DG current for the maximum loss saving is:

$$I_{DG} = -\frac{\sum_{i=1}^{n} D_i I_{ai} R_i}{\sum_{i=1}^{n} D_i^2 R_i} = -\frac{\sum_{i\in\beta} I_{ai} R_i}{\sum_{i\in\beta} R_i} \tag{4.8}$$

The optimum size of DG at bus *m* is:

$$P_{DG} = V_m \times I_{DG} \tag{4.9}$$

where, V_m is the voltage magnitude of the bus *m*. The optimum size of DG for each bus is determined using Equation (4.9). Then possible loss saving for each DG is determined by using Equation (4.6). The DG with highest value of $LRSF_i$ is identified as candidate location for single DG placement. When the candidate bus is identified and DG is placed, the above technique can also be used to identify the next and subsequent bus to be compensated for loss reduction.

4.2.3 Priority list

The buses are ranked in descending order of the values of their $LRSF_i$ to form a priority list. The top-ranked buses in the priority list are the first to be studied as alternatives location to install the DGs.

The $LRSF_i$ will reduce the solution space, which constitute the top ranked buses in the priority list. The effect of number of buses taken in priority will have effect the optimum solution obtained for some system. From the priority list one can find the optimum DG locations, which will give the lowest possible total losses and assure that the voltage in every bus are in the acceptable range and power balance within the specified limits.

4.3 Loss Reduction Index

By installing DG, line currents can be reduced, thus helping to reduce electrical line losses. To evaluate total losses we defined line losses reduction index (*LRI*) as (Raj, et al., 2008):

$$LRI = \frac{LL_{wDG}}{LL_{woDG}} \tag{4.10}$$

where, LL_{wDG} is the total line losses in the system with DG and LL_{woDG} is the total line losses in the system without DG. Based on this definition, the following attributes are:

- $LRI < 1$ DG has reduced total power losses.
- $LRI = 1$ DG has no impact on power losses.
- $LRI > 1$ DG has caused more total power losses.

This index can be used to identify the best size of DG to maximize the line loss reduction. The minimum value of *LRI* corresponds to the optimum DG size in terms of line loss reduction.

4.4 Mathematical Model

For a given radial distribution network with *n* nodes, the proposed method aims to minimize the objective function without violation of the constraints. The objective function is designed to reduce the loss reduction index. The mathematical model can be expressed as:

$$Min \quad LRI = \frac{LL_{wDG}}{LL_{woDG}} \tag{4.11}$$

Subject to:

Power balance constraints:

$$\sum_{i=1}^{n} P_{DGi} = \sum_{i=1}^{n} P_{Di} \tag{4.12}$$

Voltage constraints:

$$\left|V_i\right|_{\min} \le \left|V_i\right| \le \left|V_i\right|_{\max} \tag{4.13}$$

P_L is the total real power loss in the system, P_{DGi} is the real power generated by DG at bus *i*, P_{Di} is the power demand at bus *i*. Vi_{max} and Vi_{min} are the upper and lower limits on i^{th} bus voltage. Usually, the voltage in every bus shall be in the acceptable range 1±0.06 p.u..

4.4.1 Particle Swarm Optimization Algorithm

In n-dimensional search space, let $x_i = (x_{i1},..., x_{id} ,..., x_{in})$ and $v_i = (v_{i1},..., v_{id} ,..., v_{in})$ donate the position and velocity for the ith particle, respectively. The best previous experience of the i^{th} particle is recorded and represented as $pbest_i = (pbest_{i1},..., pbest_{id} ,..., pbest_{in})$. The best value among all individuals' experiences in the group is stored and referred as $gbest = (gbest_1,..., gbest_d ,..., gbest_n)$. The modified velocity of each particle can be calculated using the current velocity and the distance from personal best position (*pbest*) and global best position (*gbest*) as shown in the Equation (4.14). The new position of that particle can be determined by using Equation (4.15) (Niknam, 2006).

$$v_{id}^{k+1} = \omega_i v_{id}^{k} + c_1 rand_1 (pbest_{id}^{k} - \chi_{id}^{k}) + c_2 rand_2 (gbest_{d}^{k} - \chi_{id}^{k}) \qquad (4.14)$$

$$i = 1,2,...,n$$
$$d = 1,2,...,m$$

$$\chi_{id}^{k+1} = \chi_{id}^{k} + v_{id}^{k+1} \qquad (4.15)$$

In Equations (4.14) and (4.15); i=1, 2… n is the index of each particle in a group, and m is number of members in a particle. k is iteration number. $rand_1$ and $rand_2$ are random numbers between 0 and 1. The constants $C1$ and $C2$ are the acceleration coefficients, which pull each particle toward *pbest* and *gbest* positions. Low values allow particles to move far from the target region before being togged back. On the other hand, high values result in abrupt movement toward, or backward target region. Appropriate value ranges for $C1$ and $C2$ are 1 to 2, but 2 is the most appropriate in many cases. χ_{id}^{k} is

current position of agent *i* at iteration *k*, χ_{id}^{k+1} is modified position of agent *i*, v_{id}^{k} is current particle velocity of agent *i* at iteration *k*, v_{id}^{k+1} is modified velocity of agent *i*.

The inertia weight ω is used to control the convergence behavior of PSO. Suitable selection of inertia weight ω in Equation (4.14) provides a balance between global and personal explorations, thus, requiring less iteration on average to find a sufficiently optimal solution. As originally developed, ω often decreases linearly from about 0.9 to 0.4 during a run. In general, the inertia weight ω is set according to the following Equation (4.16) (Niknam, 2006):

$$\omega_i = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{\kappa_{\max}} \times \kappa \qquad (4.16)$$

where, $\omega_{\max}$ and $\omega_{\min}$ are the maximum and minimum weights respectively. *k* and k_{max} are the current and maximum iteration. Figures (4.1) and (4.2) picture the basic idea of PSO.

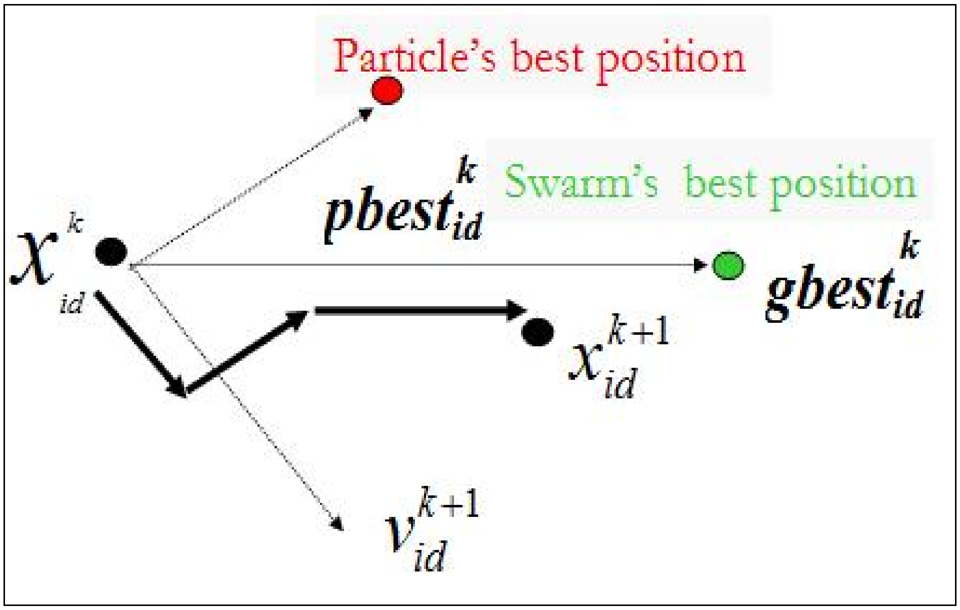

Figure 4.1: Concept of a searching point by PSO (Krueasuk and Ongsakul, 2006)

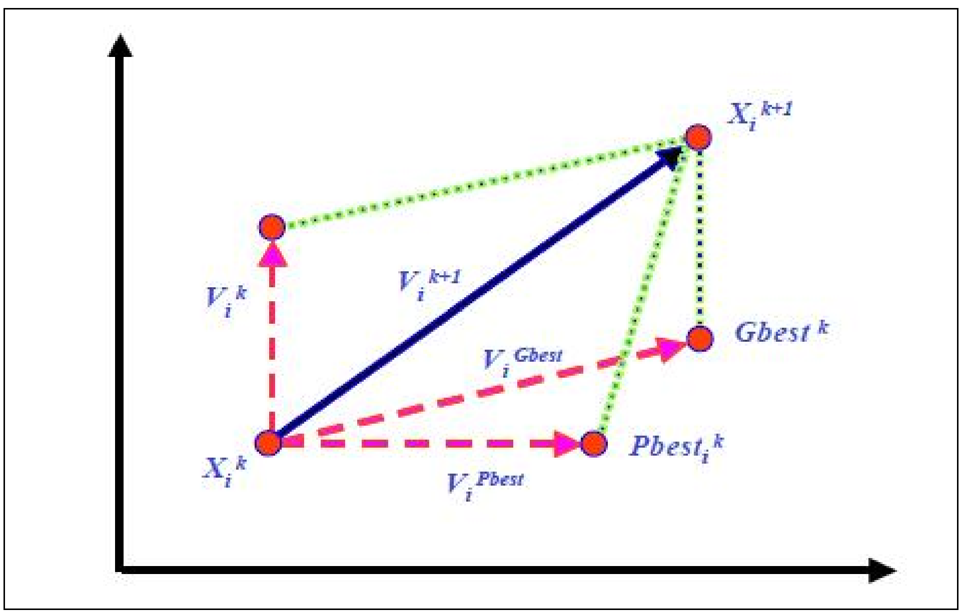

Figure 4.2: Modification of a searching point by PSO (Park, et al., 2006)

4.4.2 Assumptions and Limitations

The following assumptions and limitations are to be taken into consideration in this research:

- The penetration of DG in the distribution system is assumed to be up to 100% of the demand load.
- The network is considered to be radial with i nodes and n branches, which implies that $i = n + 1$.
- In practice, such economic, financial and geographic factors are to be considered when installing the DG. These factors are not discussed in this work.
- The DG is assumed to provide a capability of 24-hours a day.
- In fact, one type of DG is considered capable to supply only real power.
- Load changes are not taken into account.

These assumptions and limitations do not mean that DG is inappropriate for minimizing real power losses and improving the system performance of distribution system.

4.4.3 Algorithm for the Proposed Method

In the proposed method, the candidate locations to place the DGs are identified by using the LRSF technique, while PSO technique is used to calculate the DG sizes in all these obtained locations.

The general outlines for the LRSF and PSO to solve the problem of DG size and location are discussed in the previous sections. The sequential steps for solving problem are as follows:

Step 1: Input the distribution system data including bus numbers, line impedances (R and X) between buses, complex demand bus powers (P and Q) and voltage limits.

Step 2: Run the load flow for base case to compute the total power losses and voltage on buses. In the same load flow compute the optimum size of distributed generators at each bus from Equation (4.9).

Step 3: For each bus update the demand bus power after installing DG for that bus which computed in **step 2**, and calculate the new total losses and voltage.

Step 4: Find the LRSF using Equation (4.7) and arrange the buses in descending order of their sensitivity factors to form a priority list.

Step 5: Select the bus with the highest priority and place DG at that bus.

Step 6: Update the system data and is considered as base case for next iteration in the priority list.

Step 7: For the selected bus if the bus voltages and capacities of installed DGs are not violate the system constraints in Equations (4.12) and (4.13), then the DG location and size are stored. Otherwise, that bus is infeasible and go back to **step 2**.

Step 8: Randomly generates an initial population (array) of particles with random positions and velocities on dimensions in the solution space. The iteration count is set to zero.

Step 9: For each particle, placing all the DGs at the respective candidate locations and load flow analysis is performed to find the loss reduction index (*LRI*) using Equation (4.11).

Step 10: Compare the objective function value of each particle with the individual *pbest*. If the objective value is lower than *pbest*, set this value as the current *pbest*, and record the corresponding particle position.

Step 11: Choose the particle associated with the minimum *pbest* of all particles, and set the value of this *pbest* as the current overall best *gbest*.

Step 12: Update the velocity and position of particle using Equations (4.14) and (4.15) respectively.

Step 13: If the iteration number reaches the maximum limit, go to Step 14. Otherwise, set iteration index $k = k + 1$, and go back to Step 9.

Step 14: Print out the optimal solution to the target problem that the best size of DG on the optimal selected locations and the corresponding fitness value representing the minimum line reduction index value.

Step 15: Compute the minimum total losses and compare it with the total losses in the base case.

Step 16: Print out the result as presented in **steps 14** and **15**.

The procedure of the proposed algorithm that is introduced in the above steps is depicted in Flowchart as shown in the Figures (4.3) and (4.4).

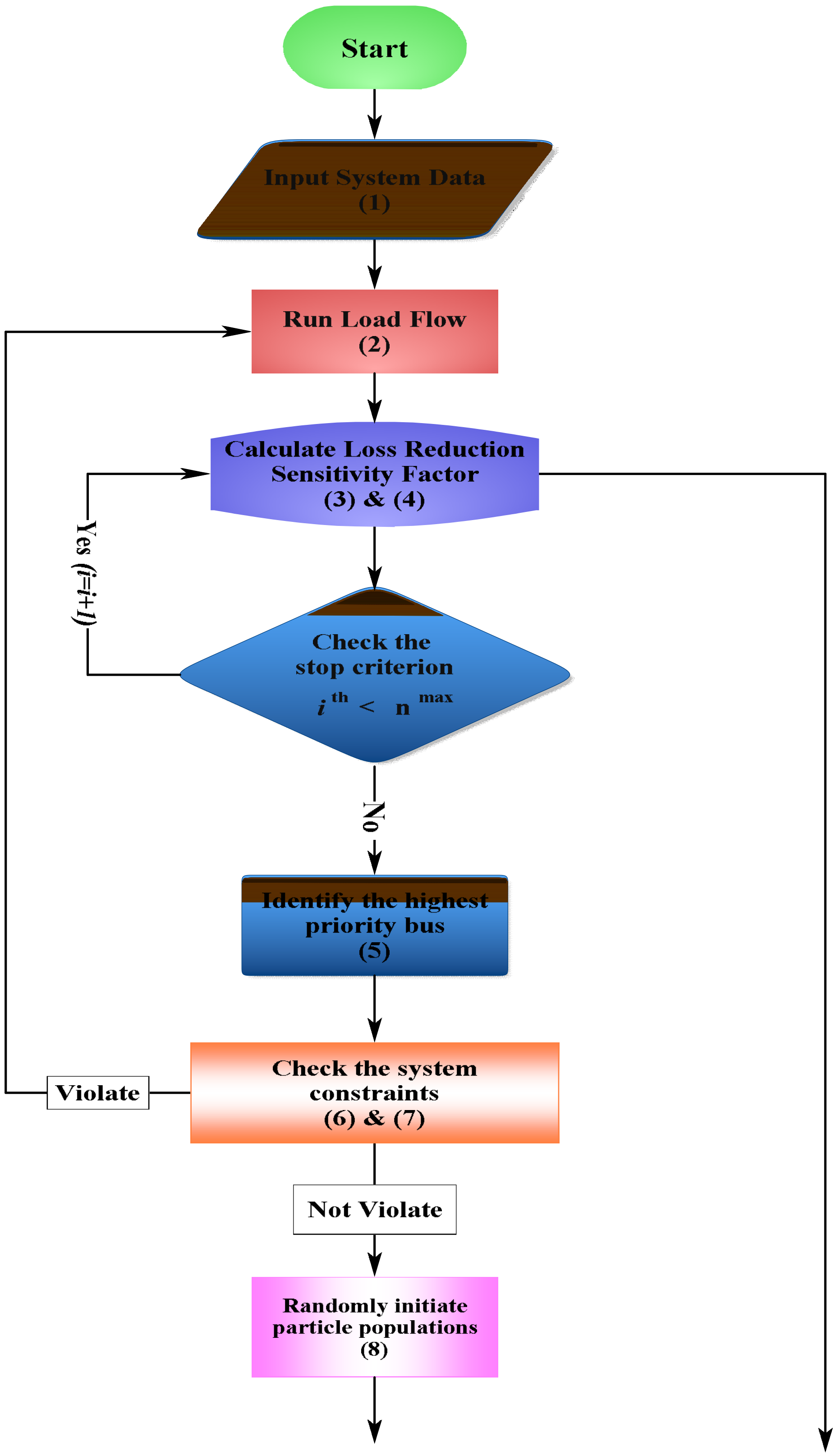

Figure 4.3: Flow chart of the proposed algorithm (Steps 1-8)

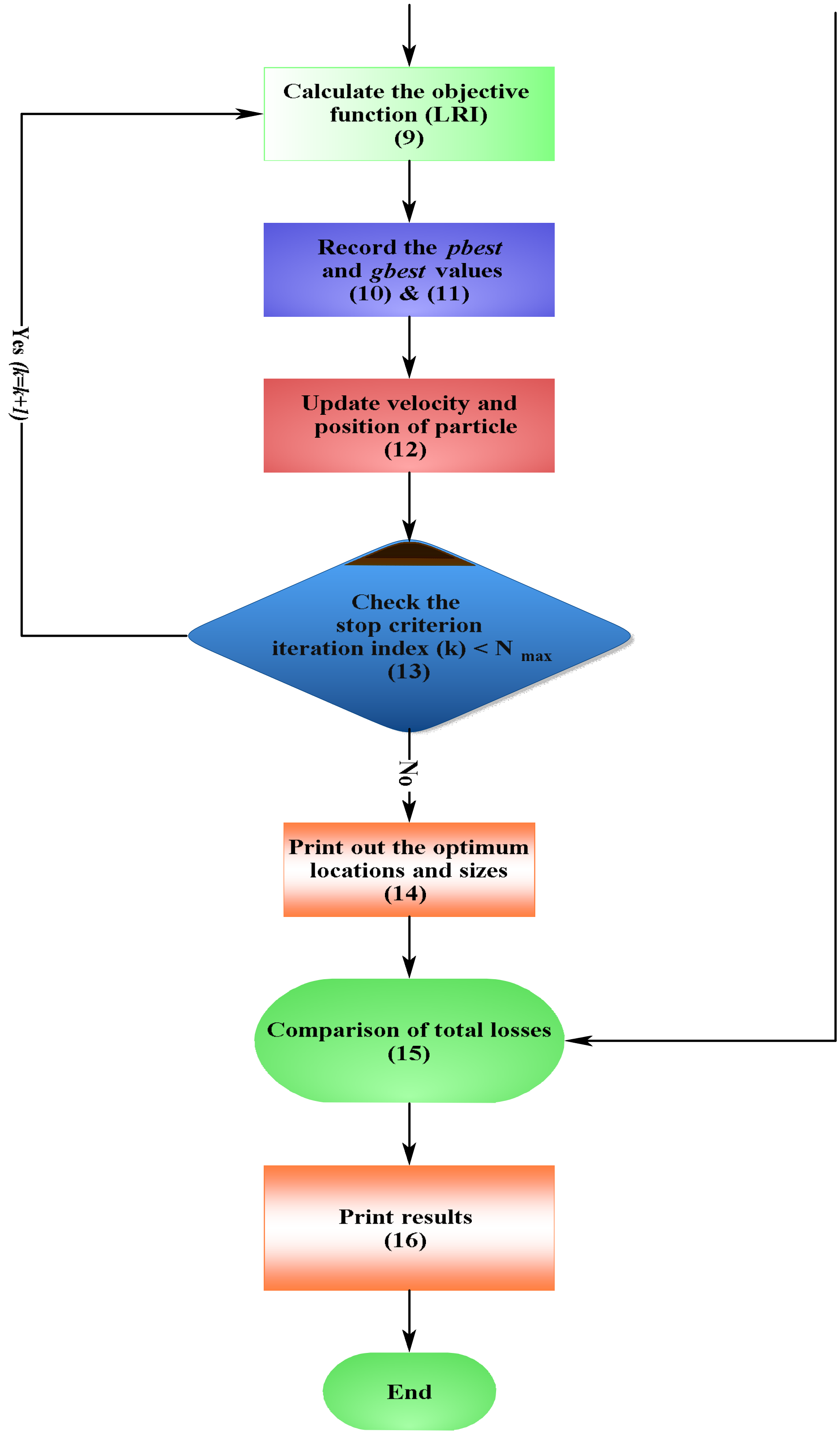

Figure 4.4: Continue flow chart of the proposed algorithm (Steps 9-16)

CHAPTER FIVE

Application of Proposed Methodology on Experimental Studies

In order to show the capability of the proposed algorithm to solve the problem of the optimal DG allocation and size in the distribution system, the simulation was carried out using MATLAB to calculate the loss saving, DG size and location for the IEEE 33-bus test system and local distribution test network. For the PSO parameters, numbers of particles are 20 particles and $C1 = C2 = 2.0$. ω_{max} and ω_{min} are set to 0.9 and 0.4 respectively.

5.1 IEEE 33-bus Distribution System

In this section a 33 bus radial distribution test system has been considered as shown in Figure (B-1) (Appendix B), where the lines and loads specification are presented in Table (A-1) (Appendix A). The 33 bus system has 32 sections with system voltage 12.66 kV. Substation bus number 1 is the slack bus. The original total real power and reactive power loads are 3.72 MW and 2.3 MVAR respectively. At first, the load flow is run and the total real power loss and reactive power loss in the system for the base case are 211.1 kW and 150.18 kVAR, respectively. And also the voltage profile for the base case is obtained as shown in Figure (5.1); one can notice that the distribution network has a typical feature that the voltages at buses reduces if moved away from substation.

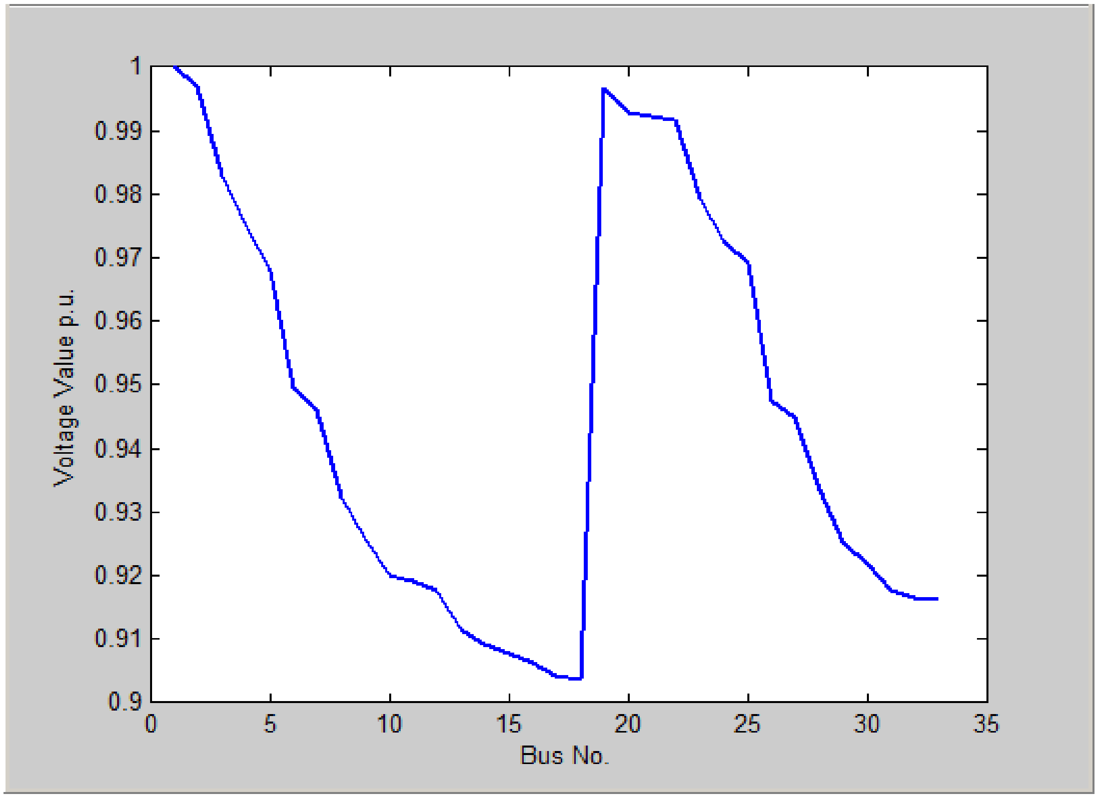

Figure 5.1: Voltage profile for IEEE 33-bus distribution system in the Base Case

5.1.1 Optimal Location Cases

Based on the proposed method, the first step is to identify the optimal cases for DG locations in the distribution system by using LRSF approach, while the voltage and power balance constraints are included in the algorithm. The results are shown in Table (5.1).

Table 5.1: Results of optimum cases to install DGs for IEEE 33-bus system

Optimum Case	Bus No. Location
Case 1	6
Case 2	6
	15
Case 3	6
	15
	25

The results in Table (5.1) show three possible cases to install DGs in the tested 33 bus radial distribution system, which lead to the minimum value of total real power losses and satisfying all of the system constraints. In the first case the optimum location to install the DG is at bus 6. It is found by calculating the local optimum sizes and the total power losses at all nodes except the slack bus and then select the highest bus in the priority list that has minimum total real losses as shown in Figure (5.2).

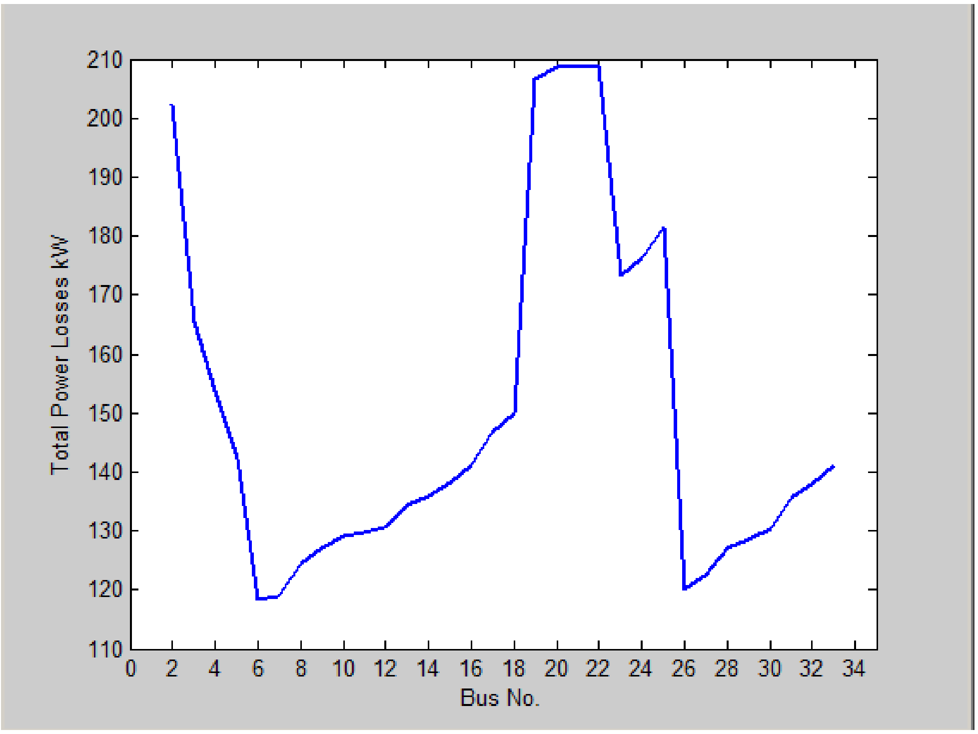

Figure 5.2: Total power losses of 33 bus distribution system in the first case

From Figure (5.2) one can conclude that the minimum loss in case of installing one DG can be achieved by selecting bus 6.

The second case can be found by placing DG at optimum location at bus 6 and be considered as base case. In this stage, the second priority bus location to be installed along with the first candidate location in case one in order to obtain the minimum losses is bus 15 as shown in Figure (5.3).

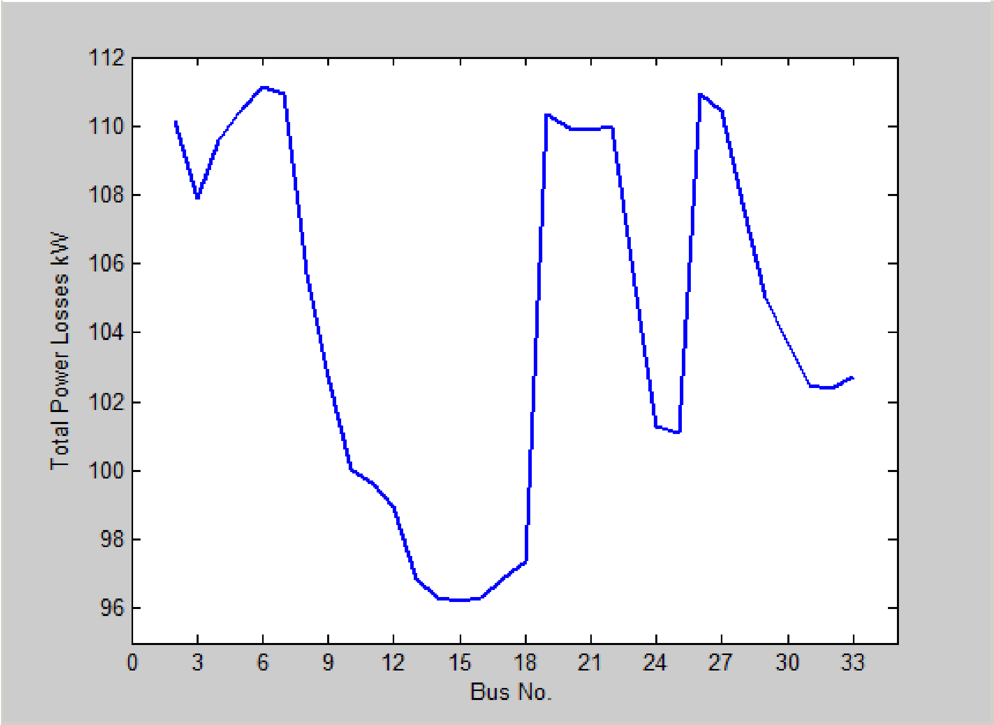

Figure 5.3: Total power losses of 33 bus distribution system in the second case

This process is repeated while all constraints meet together to find all the optimum cases to install DGs on the distribution system which efficiently minimizing the total real power loss. In this experimental study a three possible optimal solutions to place the DGs are considered. First case only one DG is installed at bus 6. In the second case two DGs are placed at bus 6 and 15. And in the last case three DGs are located at bus 6, 15 and 25.

5.1.2 Optimal Sizes of Distributed Generation

Now, according to the proposed method, the second step is to identify the optimum size of DG corresponding to global optimum solution that would lead to the least total power losses by using PSO technique. The candidate locations for DG placement are taken from optimal cases in Table (5.1). Optimal DG sizes in the three optimal cases, total real

power losses before and after installing DG, loss saving and loss reduction index are given in Table (5.2).

Table 5.2: Results of optimum DGs sizes at optimal locations for 33-bus system

Case No.	Bus No.	DG Size (MW)	Total DG Size (MW)	Losses Before Installing DG (kW)	Losses After Installing DG (kW)	Loss Saving (kW)	Loss Reduction Index
1	6	2.5918	2.5918	211.1	111	100.1	0.5258
2	6	1.9362	2.5512		91.5	119.6	0.4335
	15	0.6151					
3	6	1.7226	3.1185		80.8	130.2	0.3830
	15	0.6151					
	25	0.7808					

A simulation for searching space and the convergence characteristic of the best solution of PSO for cases one, two and three at sequential iterations are shown in Figures (C-1) to (C-18) (Appendix C).

5.1.3 Voltage Profile

Voltage profile improvement has been achieved by installing DGs. In the base case the minimum voltage is 0.9038 p.u. at bus 18. In case one the voltage at bus 18 has improved to 0.9424 p.u.. The voltage profile before and after placing the DGs for all cases are shown in Figure (5.4).

The minimum voltage and improvement in minimum voltage compared to base case are shown in Table (5.3).

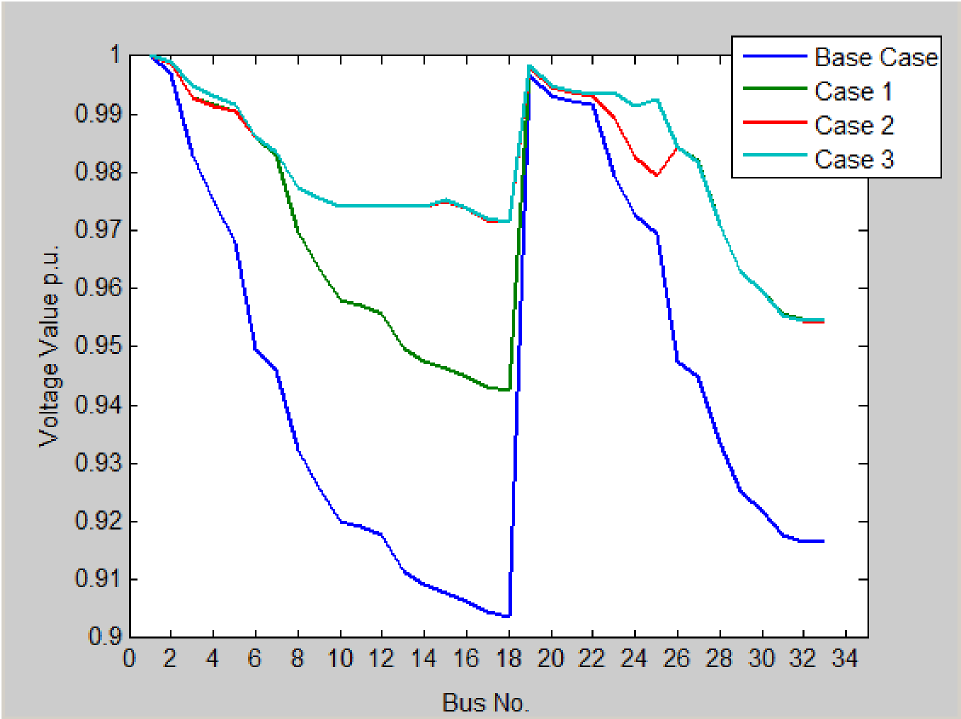

Figure 5.4: Voltage profile for before and after installing DGs for 33-bus system

Table 5.3: Voltage profile improvement in 33-bus system

Method and Case No.	**Bus No.**	**Minimum Voltage (p.u.)**	**% improvement**
Base case	18	0.9038	
Case 1	18	0.9424	4.27 %
Case 2	33	0.9543	5.59 %
Case 3	33	0.9544	5.60 %

5.2 Local Distribution Tested Network

Local distribution network from Irbid District Electricity Company (IDECO) was selected from one part of the Jordanian distribution system. Single line diagram of the selected network is shown in Figure (B-2) (Appendix B). This network is an open radial distribution system feeds from 132/33 kV substation. It is has a 174 buses and 173 sections with system voltage 33kV. Table (A-2) (Appendix A) illustrates line and bus information.

Substation (S/S) is the slack bus and given number 1. The original total real power and reactive power loads are 10.265 MW and 6.120 MVAR respectively. The original total real power loss and reactive power loss in the system are 535 kW and 744.6 kVAR respectively. The voltage profile is shown in Figure (5.5).

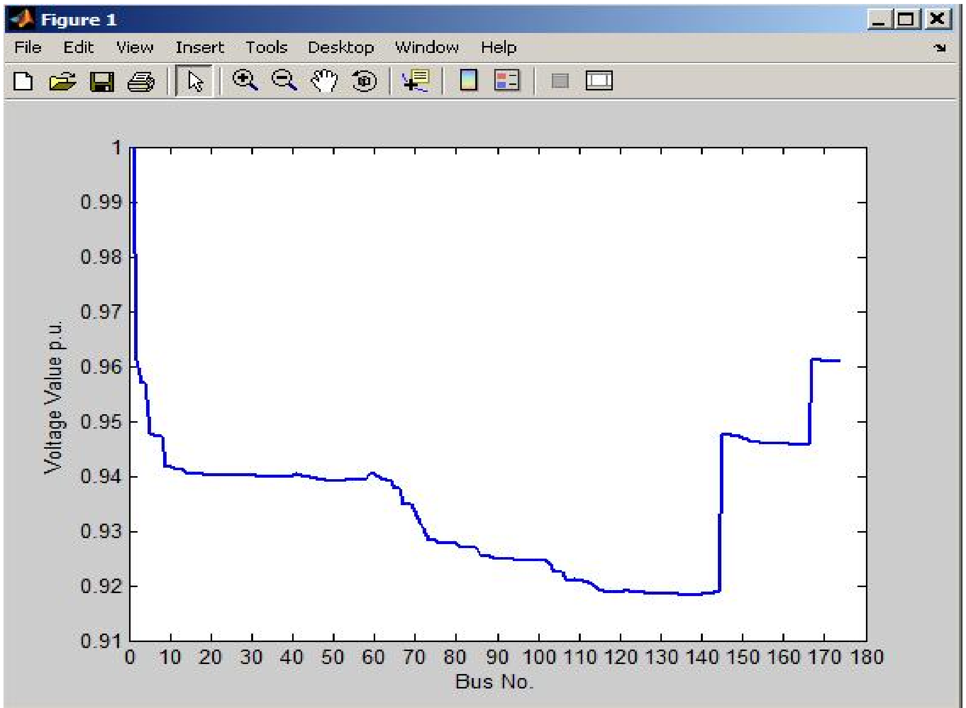

Figure 5.5: Voltage profile for local distribution network in the base case

Irbid District Electricity Company conducted a study on the selected local distribution network to minimize the losses and improve the voltage profile by using a strong analyzer program called CYME. The CYME Distribution Analysis program is designed for planning studies and simulating the behavior of electrical distribution networks under different operating conditions and scenarios. It includes several built-in functions that are required for distribution network planning, operation and analysis. The analysis functions such as load flow, short-circuit and network optimizations, are performed on balanced or unbalanced distribution network that are built with any combination of phases and configurations.

The results are obtained by CYME suggest to place two capacitor bank to reduce the losses and improve the voltage level, while respecting the user-defined constraints such as voltage thresholds and loading limits. The results are shown in Table (5.4).

Table 5.4: Results of IDECO's study after installing capacitor banks in the local distribution network

Locations of Capacitors (Bus No.)	Total Capacitors Size (MVAR)	Losses Before Installing Capacitors (kW)	Losses After Installing Capacitors (kW)	Loss Saving (kW)	% Saving
12	1.094	534.4	486	49	9.2
70					

From the above Table it is clear that only 49 kW loss saving has been achieved due to install two capacitors bank with total capacity equals 1.094 MVAR. The voltage improvement before and after installing capacitor banks are shown in Figure (5.6).

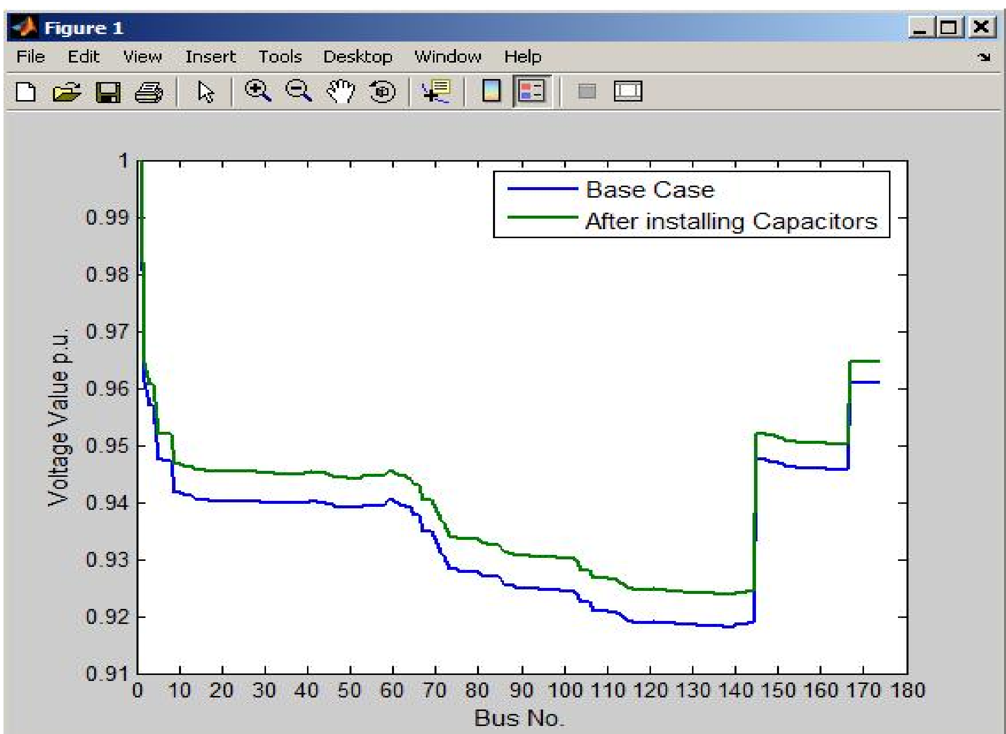

Figure 5.6: Voltage profile for local distribution system before and after installing capacitor banks

It is clear from Figure (5.6) that the lowest voltage for base case is at bus 139 with value equal 0.9181 p.u.. After installing capacitor banks the voltage at bus 139 has increased to 0.9239 p.u..

5.2.1 Optimal Location Selection

The results shows two optimal cases to place the DG in order to minimize the total real power losses while the voltage and power balance constraints are obtained in the proposed algorithm. The first case is to install one DG at bus 71 and the second case is to install two DGs at buses 71 and 42. The results are shown in Table (5.5).

Table 5.5: Results of optimum cases to install DGs for local distribution network

Optimum Case	Bus No. Location
Case 1	71
Case 2	71
	42

5.2.2 Sizes Allocation

The optimum size of DG can be found by using PSO technique. Table (5.6) illustrated the optimal size of DG sizes in the two optimal cases in addition to the total real power losses before and after installing DG, loss saving and loss reduction index.

Table 5.6: Results of optimum sizes of DGs for local distribution network

<table>
<tr><th>Case No.</th><th>Bus No.</th><th>DG Size (MW)</th><th>Total DG Size (MW)</th><th>Losses Before Installing DG (kW)</th><th>Losses After Installing DG (kW)</th><th>Loss Saving (kW)</th><th>Loss Reduction Index</th></tr>
<tr><td>1</td><td>71</td><td>8.7780</td><td>8.7780</td><td rowspan="3">534.4</td><td>179.74</td><td>354.7</td><td>0.3364</td></tr>
<tr><td rowspan="2">2</td><td>71</td><td>6.0845</td><td rowspan="2">9.8212</td><td rowspan="2">158.13</td><td rowspan="2">376.27</td><td rowspan="2">0.2959</td></tr>
<tr><td>42</td><td>3.7367</td></tr>
</table>

From Table (5.6) it is clear that they are two possible cases to install DGs in the local radial distribution system. The first one is to install one DG at bus 71 with capacity size 8.7780 MW and the second case is to install two DG at buses 71 and 42 with size of 6.0845 and 3.7367 respectively.

A simulation for searching space and the convergence characteristic of the best solution of PSO for cases one, two and three at sequential iterations are shown in Figures (C-19) to (C-30) (Appendix C).

5.2.3 Voltage Profile

Installing of DGs has improved the voltage profile for the tested local distribution network. In the base case the minimum voltage is 0.9182 p.u. at buses 136. In case one the voltage has improved at buses 136 to 0.9574 p.u.. Case two has further improved the voltage at buses 136 to 0.9576 p.u. The improvement in the voltage profile after optimally placing the DGs for all cases is as shown in Figure (5.7).

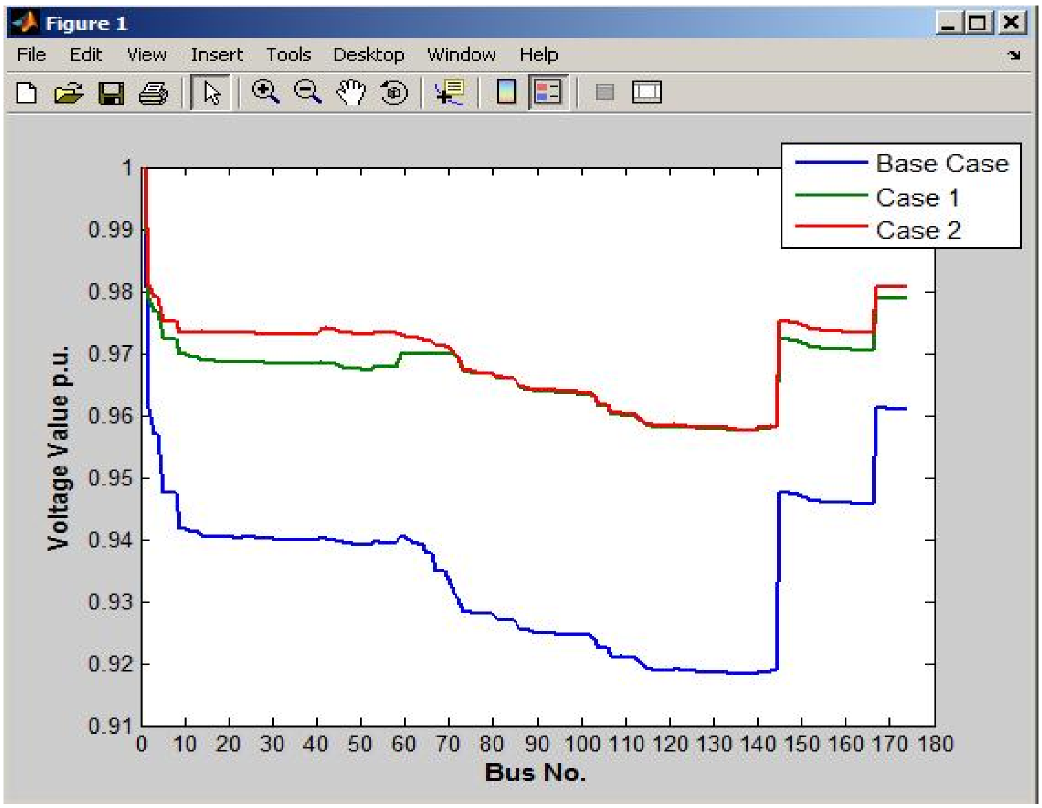

Figure 5.7: Voltage profile for local network before and after installing DGs

5.2.4 Comparison of Proposed Method and IDECO's Study

The optimization results and comparisons for the proposed method and IDECO's study are presented in Table (5.7).

Table 5.7: Optimization results and comparisons for the proposed method and IDECO's study.

Method and Case No.	Bus No.	Losses for Base Case (kW)	Loss Saving (kW)	Loss Reduction
IDECO's study with Capacitor Banks	12	534.4	49	9.2 %
	70			
Proposed method with DGs **Case one**	71		354.7	66.4 %
Proposed method with DGs **Case two**	71		376.27	70.4 %
	42			

For the tested local distribution systems, in Tables (5.7), the proposed method can obtain a tangible improvement in total power losses. The proposed method can reduce the total real power loss by 66.4% for case one and further reduce to 70% in case two compared to 9.2% for IDECO's study.

The comparisons of voltage profile improvement for the proposed method, IDECO's study and base case are shown in Figure (5.8).

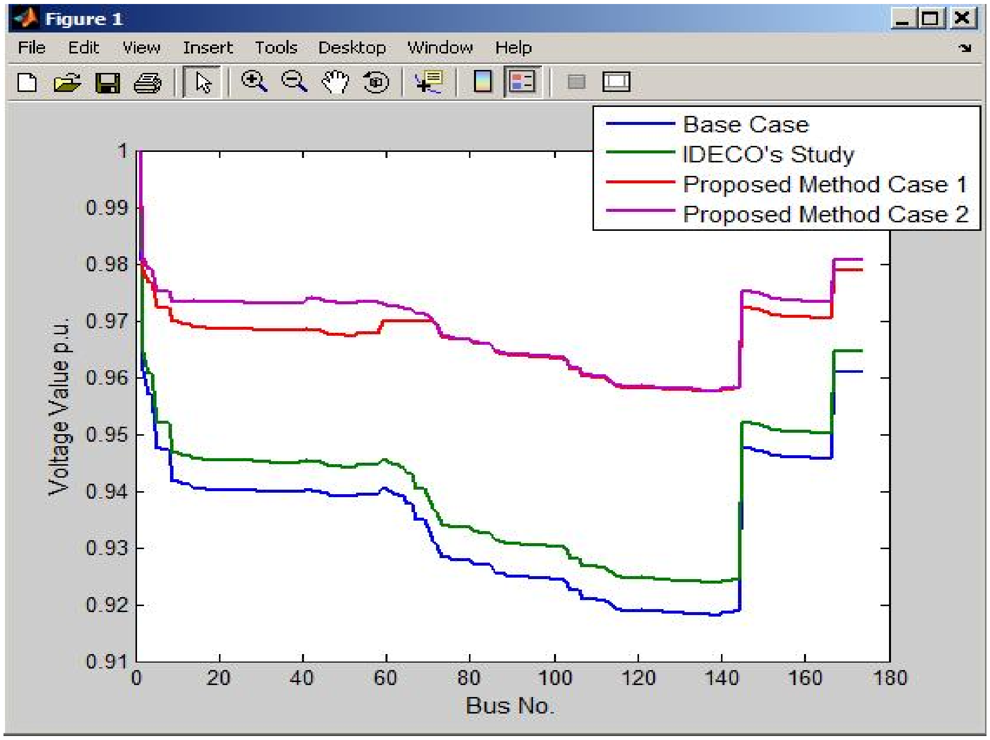

Figure 5.8: Voltage profile improvement for all presented cases for local network

Table (5.8) illustrates the minimum voltage and improvement value in voltage profile for all presented cases.

Table 5.8: Results comparison of voltage profile improvement in local network

Case No.	Bus No.	Minimum Voltage (p.u.)	Improvement
Base case	138-139	0.9181	
IDECO's study	136-139	0.9239	0.63 %
Case 1	136-139	0.9574	4.28 %
Case 2	136-139	0.9576	4.3 %

CHAPTER SIX

Conclusion and Future Work

This work aimed to propose a proper algorithm to investigate the optimal sizes and sittings of DG in radial distribution system in order to reduce the real power losses. This problem has been solved using proposed method as introduced in chapter four considering two steps methodology, as the optimal locations have been found by using the LRSF approach and the optimum sizes have been calculated using PSO technique. In addition, the proposed method has been coded as a Matlab M-File and carried out on IEEE 33-bus tested distribution system and local distribution network.

6.1 Conclusions

From the study the following conclusions are drawn:

- Selecting the optimal size and location of DG in radial distribution system plays an important role to reach the maximum total power losses reduction and improve the voltage profile.
- The developed algorithm is effective in deciding the optimum sizes of DG to be installed at optimum candidate locations in the distribution system while the power and voltage constraints have been obtained.
- The beneficial of the proposed algorithm that is use two steps methodology for restricting the search area for optimum size.

- Proposed method has added advantage of easy implementation and programming.

- The proposed method is suitable for single or multiple DG placements.

- Results proved that the optimal size and location of a DG can save a huge amount of power. For the IEEE 33 bus tested system, power losses are reduced from 47.4 % in single DG placement to more than 61.7 % in multi DG placement. In the local tested network, losses are reduced from 66.4 % in single DG placement to more than 70.4 % in multi DG placement.

- The Jordanian utilities shall consider the sitting of DG, in addition to other methods (i.e. placement of capacitor banks) in their studies for loss minimization and voltage profile improvement in distribution system.

- Placement of DG can obtain results better than capacitor banks in distribution system for minimizing real power losses and improving the voltage level.

6.2 Future Work

The following fields are suggested for future work:

- Optimal placement of DG on the reliability of distribution system and energy efficiency solved by suitable optimization technique.

- Cost evaluation of integrated DG in the distribution network considering installation costs, operation cost, and losses cost.

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APPENDIX A

A.1 System Data for IEEE 33-bus Distribution System

Table A-1: System data of tested IEEE 33-bus distribution system

Starting Bus	Ending Bus	Line R Ohms	Line X Ohms	Real Power (KW)	Reactive Power (KVAR)
1	2	0.0922	0.0470	100	60
2	3	0.4930	0.2511	90	40
3	4	0.3660	0.1864	120	80
4	5	0.3811	0.1941	60	30
5	6	0.8190	0.7070	60	20
6	7	0.1872	0.6188	200	100
7	8	1.7114	1.2351	200	100
8	9	1.0300	0.7400	60	20
9	10	1.0440	0.7400	60	20
10	11	0.1966	0.0650	45	30
11	12	0.3744	0.1238	60	35
12	13	1.4680	1.1550	60	35
13	14	0.5416	0.7129	120	80
14	15	0.5910	0.5260	60	10
15	16	0.7463	0.5450	60	20
16	17	1.2890	1.7210	60	20
17	18	0.7320	0.5740	90	40
18	19	0.1640	0.1565	90	40
19	20	1.5042	1.3554	90	40
20	21	0.4095	0.4784	90	40
21	22	0.7089	0.9373	90	40
22	23	0.4512	0.3083	90	50
23	24	0.8980	0.7091	420	200
24	25	0.8960	0.7011	420	200
25	26	0.2030	0.1034	60	25
26	27	0.2842	0.1447	60	25

27	28	1.0590	0.9337	60	20
28	29	0.8042	0.7006	120	70
29	30	0.5075	0.2585	200	600
30	31	0.9744	0.9630	150	70
31	32	0.3105	0.3619	210	100
32	33	0.3410	0.5302	60	40

Note: Bus 1 is a slack bus

A.2 System Data for Local Distribution Network

Table A-2: System data of tested local distribution network

No.	Equipment No	Line R Ohms	Line X Ohms	Real Power (kW)	Reactive Power (kVAR)
1	S/S	1.95	3.14	3662	2373.5
2	00013400	1.95	3.14	3662	2373.5
3	00013407	0.25	0.28	3433.2	2153.6
4	00013408	0.05	0.05	0	0
5	00013409	0.55	0.64	3421.4	2140.9
6	00013410	0.01	0.01	3054.1	1939.8
7	00013411	0.01	0.01	3032.8	1927.7
8	00013412	0.02	0.01	115.3	44.4
9	00013416	0.38	0.44	2917	1882.9
10	1565	0.03	0.03	984.4	571.3
11	1566	0.08	0.05	984.3	571.3
12	3898	0.07	0.08	984	571.2
13	1571	0.02	0.02	983.7	571.1
14	00013424	0.2	0.13	983.7	571.1
15	00013425	0.05	0.03	276.7	171.9
16	13228	0.03	0.02	276.7	171.9
17	00013427	0.09	0.06	241.4	160.8
18	00013428	0.16	0.1	238.3	157.5
19	00013429	0.15	0.1	72.5	47.3
20	00013430	0.03	0.02	3.6	0
21	00013431	0.04	0.04	68.9	47.6
22	00013432	0.19	0.22	65.3	49.2

23	13221	0.18	0.21	3.6	0
24	00013433	0.14	0.16	3.4	0
25	00013434	0.06	0.07	1.3	0
26	13222	0.17	0.2	0.2	0
27	00013436	0.2	0.12	165.8	110.4
28	1572	0.06	0.04	107.4	71.5
29	00013437	0.26	0.29	107.4	71.6
30	00013438	0.67	0.43	22.6	16.9
31	00013439	0.3	0.34	84.8	55.4
32	13213	0.27	0.31	70.4	47.5
33	6678	0.14	0.16	55.2	39.6
34	00013440	0.17	0.19	55.2	40
35	13211	0.02	0.02	52.2	40.1
36	6679	0.07	0.08	0.6	0
37	00013441	0.32	0.37	0.6	0
38	6703	0.06	0.07	51.6	41.1
39	6704	0.01	0.01	15.2	8.7
40	13215	0.14	0.17	14.4	8.8
41	00013443	0.11	0.07	706.1	399
42	00013444	0.15	0.1	685	381
43	00013445	0.15	0.09	618.3	334
44	00013446	0.02	0.02	92.1	62.5
45	00013447	0.43	0.28	526	271.5
46	00013448	0.2	0.13	378.1	184.5
47	00013449	0.59	0.38	171.8	115.4
48	00013450	0.06	0.04	7.4	-0.1
49	00013451	0.16	0.1	164.3	116.2
50	13254	0.58	0.67	136.6	103.3
51	00013452	0.14	0.16	89.8	74.9
52	13255	0.3	0.35	46.8	30
53	00013453	0.21	0.24	206.2	69.4
54	00013454	0.01	0.01	91.2	3.9
55	13251	0.35	0.22	114.9	66.1
56	00013455	0.02	0.02	114.9	67
57	00013456	0.34	0.22	29.5	0.2
58	13253	0.13	0.14	0	0
59	1570	0.11	0.07	1918.7	1296.8
60	00013417	0.02	0.03	1916.8	1295.8
61	00013418	0.06	0.07	1913.1	1295.4

62	00013419	0.06	0.07	1901.2	1289.4
63	00013420	0.02	0.03	39.6	30.4
64	00013421	0.05	0.05	1860.6	1258
65	00013422	0.14	0.16	1815.4	1249.6
66	00013423	0.06	0.07	69.4	19.5
67	00013457	0.35	0.4	1744	1228.1
68	00013459	0.04	0.04	75.7	48.6
69	00013460	0.09	0.11	51.8	34.2
70	3895	0.15	0.17	1663.3	1175
71	00013461	0.27	0.31	1661.4	1173.2
72	00013462	0.17	0.19	1544	1085.3
73	00013463	0.4	0.46	1522.5	1066.1
74	00013476	0.02	0.02	1509.7	1054.2
75	00013477	0.32	0.52	29.9	17.8
76	00013478	0.08	0.1	1479.6	1036.1
77	00013479	0.08	0.09	33.7	26.8
78	13250	0.15	0.18	15.2	10.6
79	00013480	0.01	0.01	15.2	11.1
80	13252	0.02	0.03	0	0
81	00013481	0.15	0.18	1445	1008.6
82	00013482	0.1	0.12	134.3	88.4
83	1573	0.08	0.09	108.8	68.3
84	00013483	0.3	0.19	108.8	68.5
85	00013484	0.58	0.67	2.8	0
86	00013485	0.34	0.39	1309.2	918.9
87	00013486	0.09	0.1	45.5	35.9
88	00013487	0.21	0.24	160.7	102.6
89	00013488	0.56	0.65	90.8	51.5
90	00013489	0.38	0.44	75.4	36.5
91	00013490	0.07	0.04	19.9	0
92	6363	0.49	0.31	0.1	0
93	00013491	0.31	0.2	55.5	38
94	00013492	0.12	0.08	0	0
95	00013493	1.02	0.64	55.5	38.6
96	00013494	0.29	0.19	48.4	34.1
97	13237	0.26	0.3	0.9	0
98	13238	0.22	0.14	47.5	35
99	00013495	0.71	0.45	46.6	37.1
100	1574	0.47	0.3	40.6	33.1

101	00013496	0.17	0.2	40.6	33.7
102	13239	0.71	0.82	0.9	0
103	00013497	0.4	0.46	1100.2	778.2
104	00013498	0.37	0.42	1083.7	760.6
105	00013499	0.02	0.02	108.6	89.4
106	00013500	0.07	0.08	0	0
107	00013501	0.38	0.43	973	670.1
108	00013502	0.64	0.74	28	22.9
109	00013503	0.3	0.34	3	2.6
110	00013504	0.03	0.03	940.3	643.7
111	00013505	0.04	0.05	916.9	621.4
112	00013506	0.24	0.15	100.3	65.7
113	00013507	0.14	0.16	816.4	555.7
114	13233	0.12	0.14	816	555.6
115	00013508	0.36	0.42	790.9	539.7
116	00013509	0.03	0.03	156	98
117	00013510	1.09	0.69	94.8	54.8
118	00013511	0.2	0.22	81.7	44.7
119	00013512	0.01	0.02	24.4	14.2
120	00013513	0.49	0.56	57.3	31
121	00013514	0.63	0.4	67.5	47.2
122	00013515	0.16	0.18	566.3	394.3
123	00013516	0.29	0.18	45.8	38.6
124	00013517	0.12	0.14	520.3	355.8
125	00013518	0.03	0.04	488.2	329.9
126	00013521	0.23	0.26	11.4	6.6
127	00013522	0.14	0.16	476.8	323.4
128	00013524	0.01	0.01	401	267.5
129	00013531	0.35	0.4	142.1	72.1
130	00013532	0.02	0.02	142.1	73.4
131	00013533	0.15	0.17	0	0
132	1575	0.12	0.13	258.9	195.4
133	00013525	0.05	0.03	258.8	195.7
134	1576	0.09	0.05	214.9	162.1
135	00013526	0.12	0.14	214.9	162.2
136	00013527	0.28	0.32	158.9	115.6
137	00013528	0.27	0.31	28.1	17.8
138	00013529	0.3	0.35	15.6	8.6
139	00013530	0.39	0.45	1.7	0

140	6498	0.3	0.19	75.7	56.1
141	13236	0.34	0.39	39.2	28.9
142	6499	0.07	0.05	36.5	27.6
143	00013519	0.24	0.27	31.9	26.1
144	00013520	0.28	0.33	15	15.8
145	00013413	0.32	0.2	20.8	11.7
146	00013414	0.1	0.06	20.8	12.2
147	6335	0.37	0.23	0.2	0
148	00013464	0.18	0.21	316.9	171.7
149	13274	0.08	0.09	314.6	171.4
150	13275	0.11	0.13	16.1	11
151	1555	0.32	0.21	298.5	160.6
152	00013465	0.34	0.39	298.3	161
153	00013466	0.07	0.08	295.5	161.9
154	00013467	0.02	0.02	29.1	31.7
155	00013468	0.23	0.27	266.4	130.3
156	81	0.02	0.03	266.3	131
157	1556	0.11	0.13	248	126.2
158	1557	0.09	0.06	247.9	126.5
159	1561	0.1	0.11	247.9	126.6
160	00013469	0.13	0.08	247.9	126.9
161	00013470	0.52	0.6	5.2	1
162	00013471	0.35	0.22	185.9	115.6
163	00013472	0.14	0.09	126.6	87.4
164	00013473	0.35	0.4	59.3	28.7
165	00013474	0.04	0.05	51.1	26.7
166	00013475	0.19	0.22	8.2	3
167	1554	0.06	0.07	128.3	67.5
168	00013401	0.11	0.07	128.3	67.7
169	00013402	0.05	0.03	103.2	61.9
170	00013403	0.86	0.55	25.1	5.9
171	13261	0.22	0.14	25.1	7.2
172	00013404	0.01	0.01	17.9	10.6
173	13262	0.76	0.88	7.1	0
174	13263	0.41	0.48	2.5	0

Note: Bus 1 is a slack bus

APPENDIX B

B.1 Single Line Diagram for IEEE 33-bus Distribution System

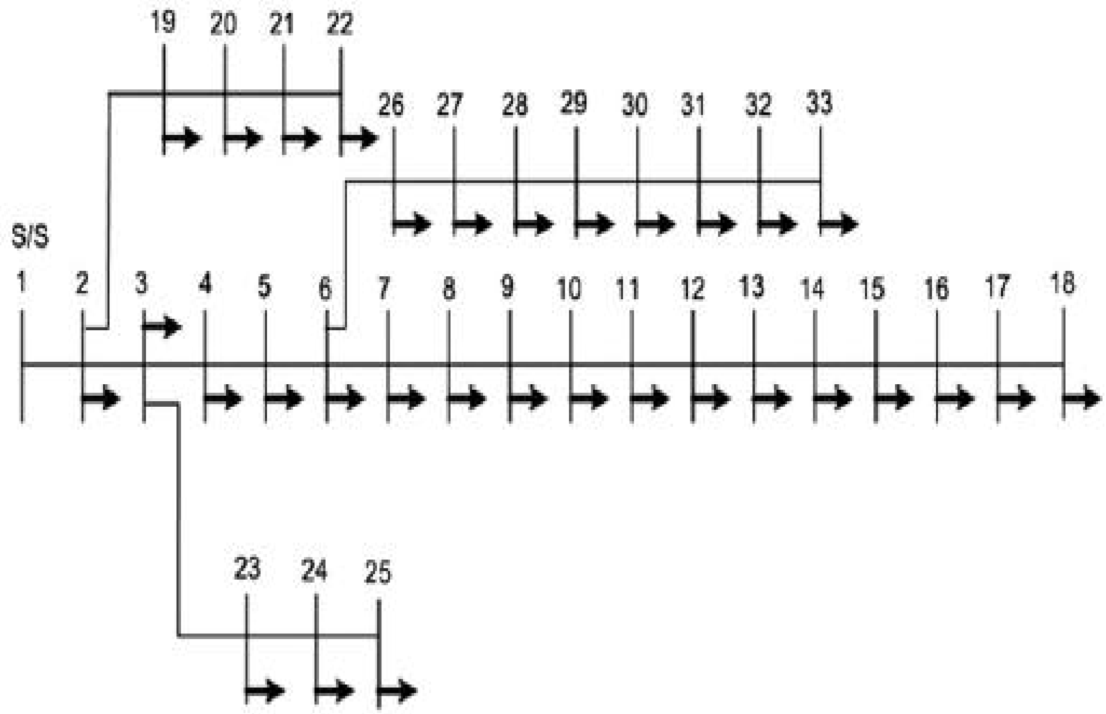

Figure B-1: Single line diagram of IEEE 33-bus radial distribution test system

B.2 Single Line Diagram Local Distribution Network

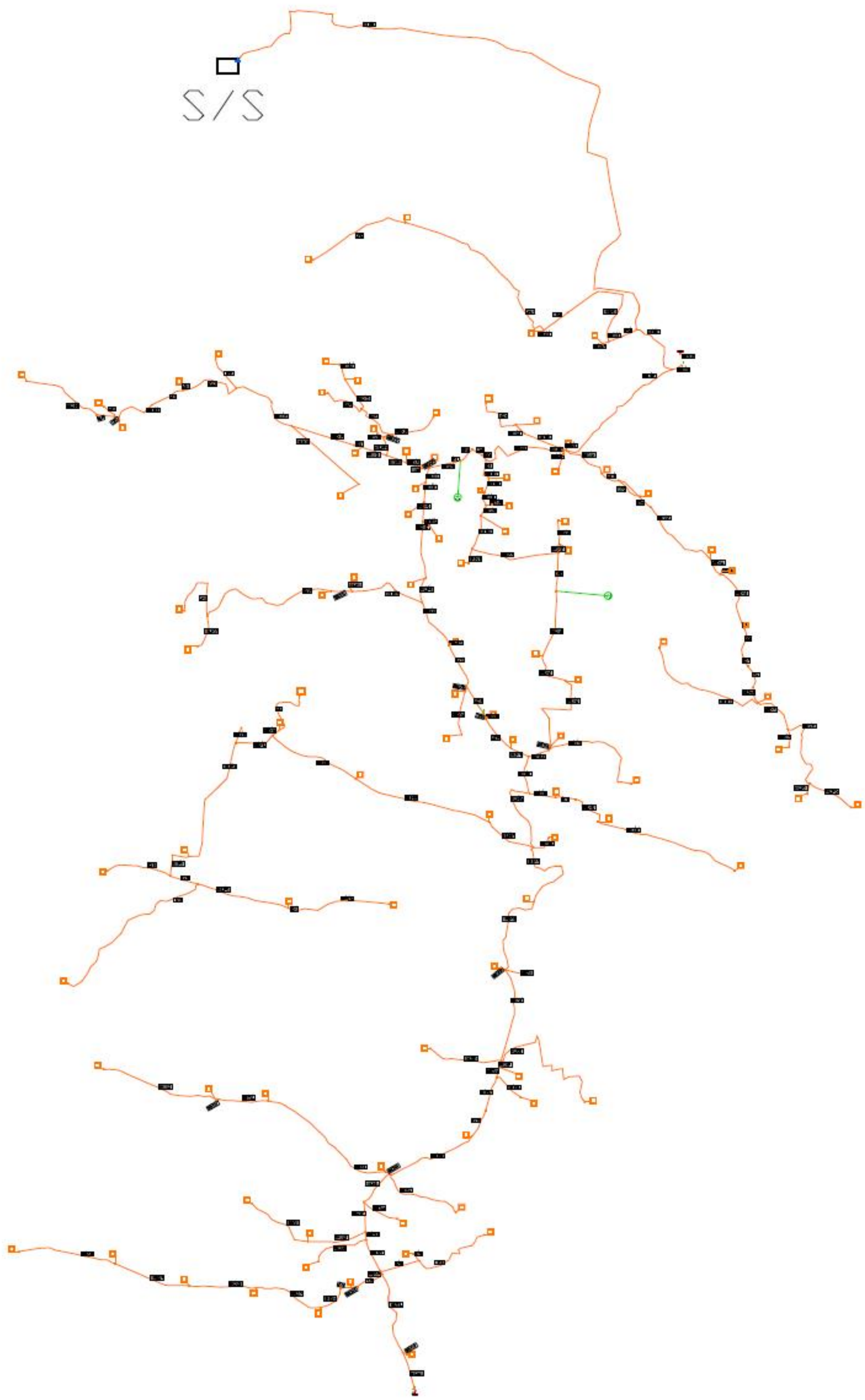

Figure B-2: Single line diagram of 33kV local distribution network

APPENDIX C

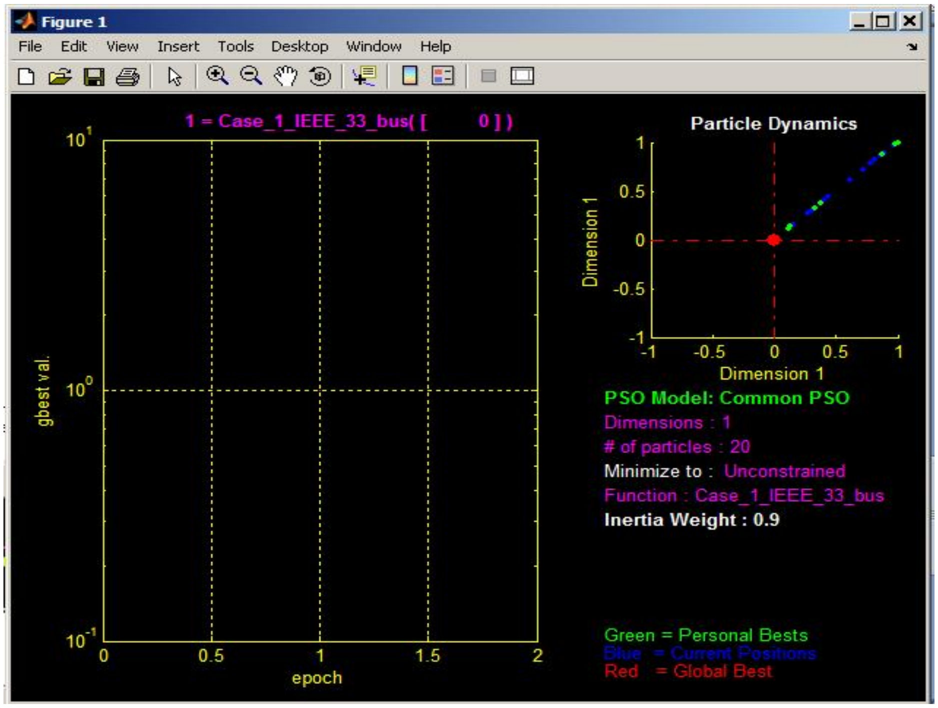

Figure C-1: Searching space for case one at first iteration

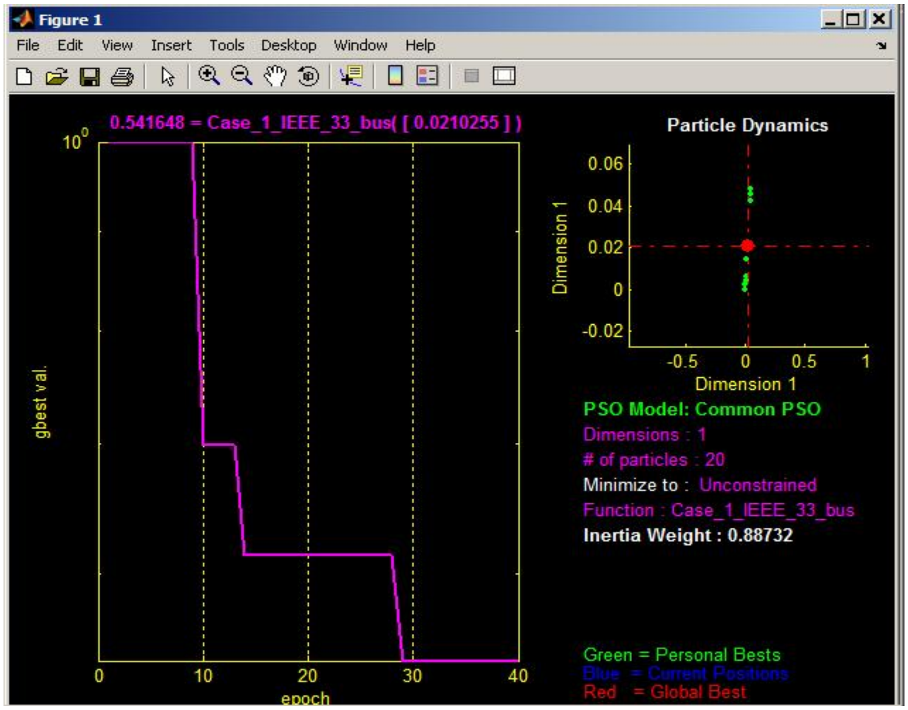

Figure C-2: Searching space for case one in 40 iterations

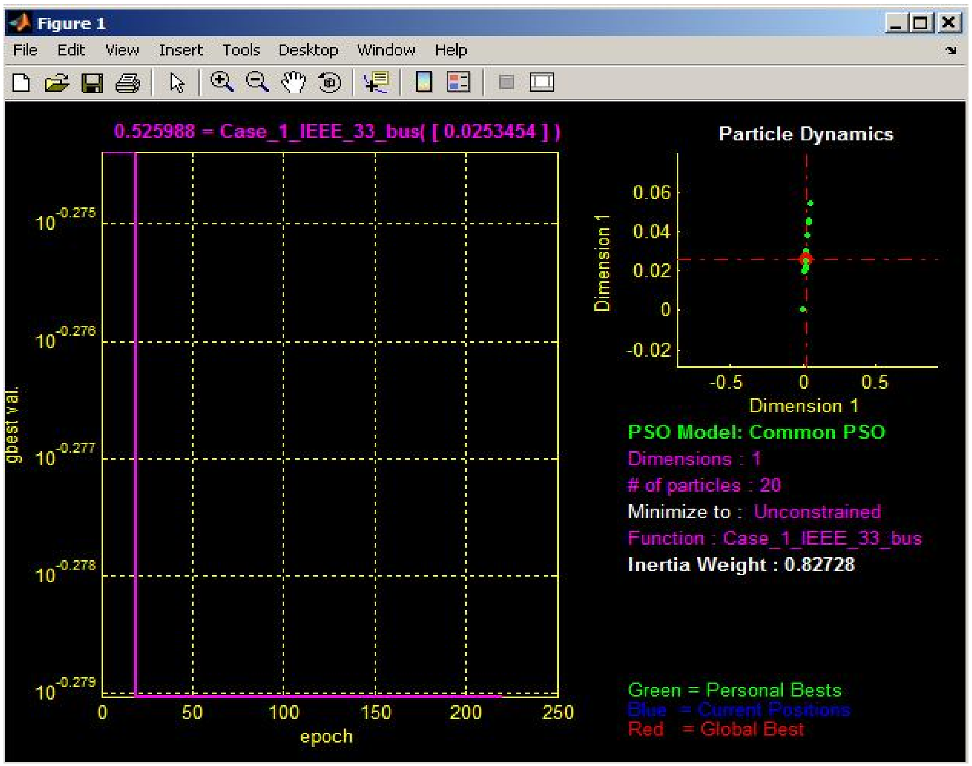

Figure C-3: Searching space for case one after 200 iterations

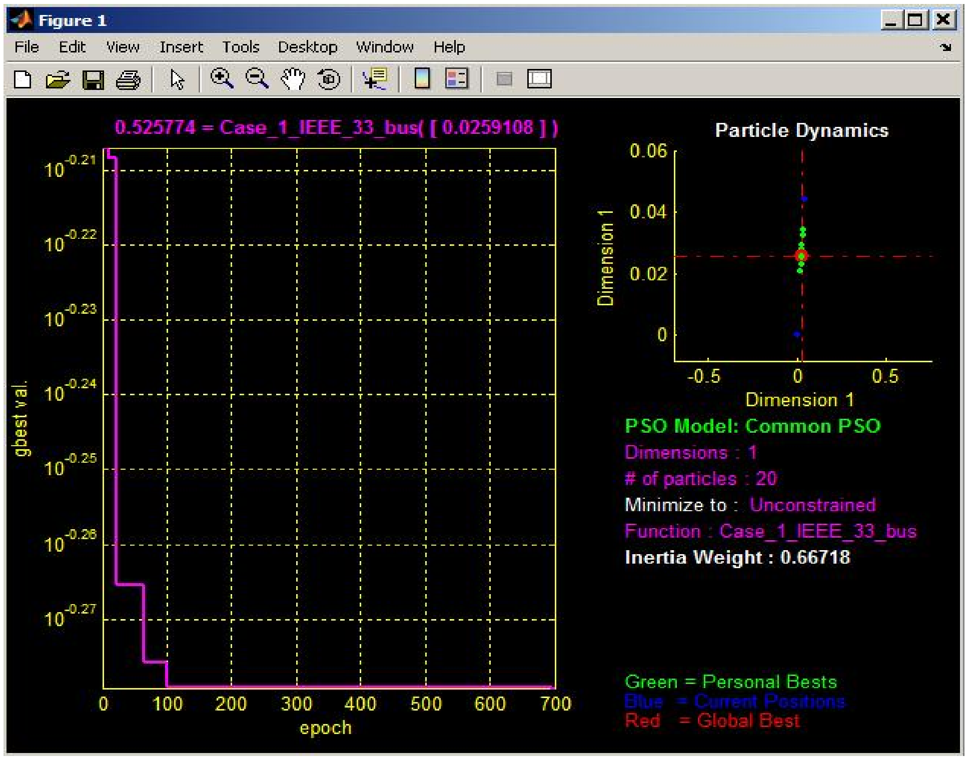

Figure C-4: Searching space for case one in 700 iterations

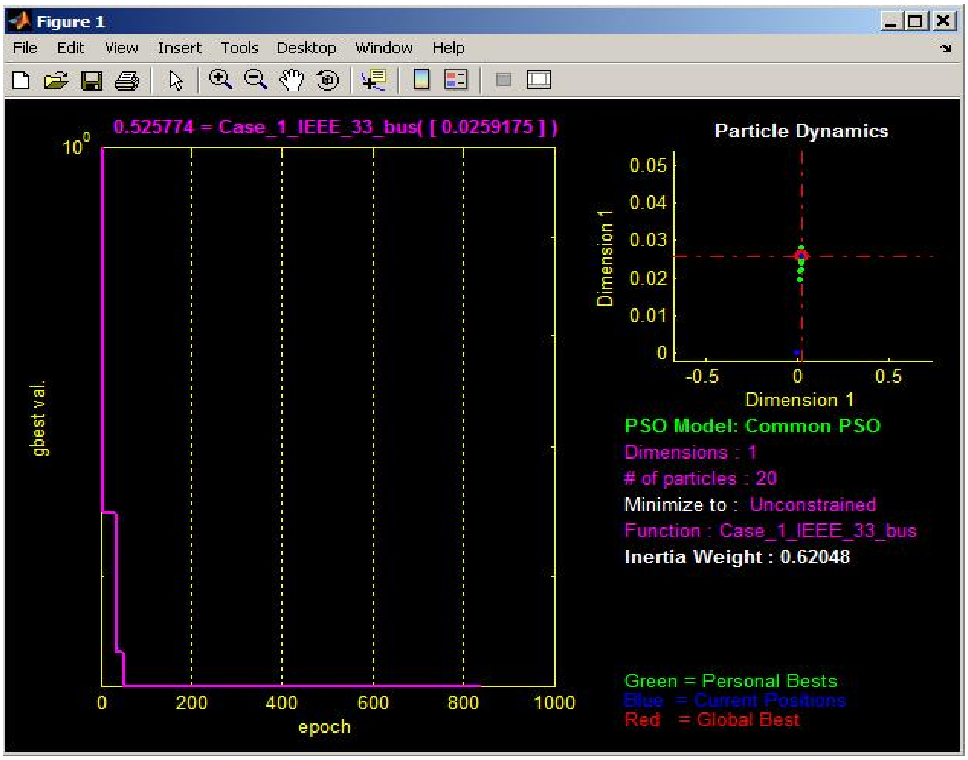

Figure C-5: Searching space for case one after 800 iterations

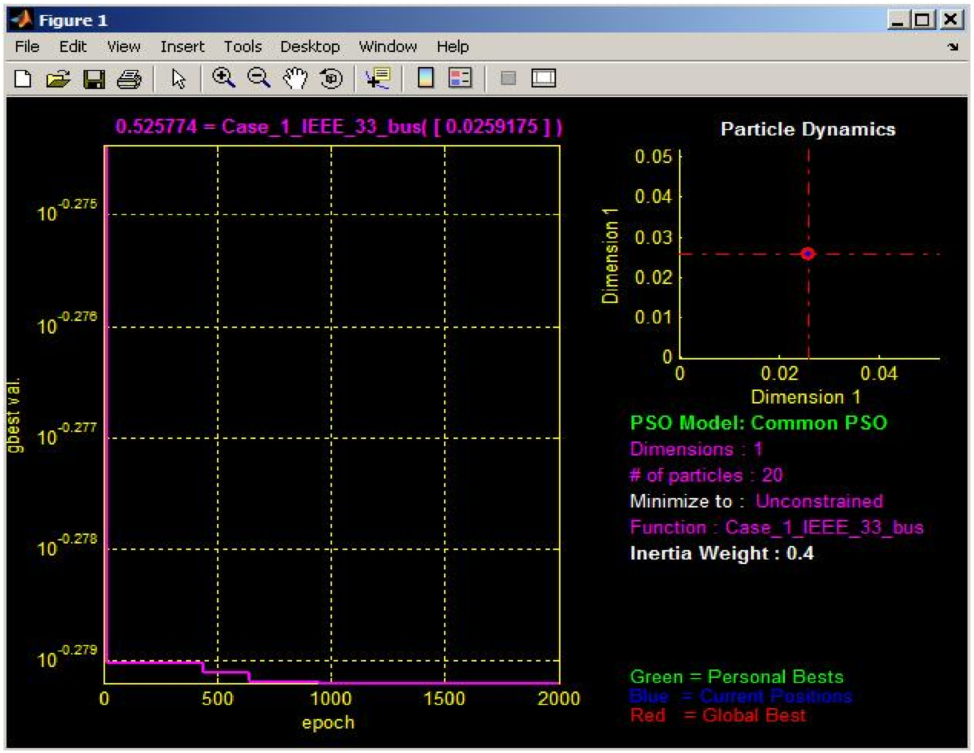

Figure C-6: Searching space for case one in 2000 iterations

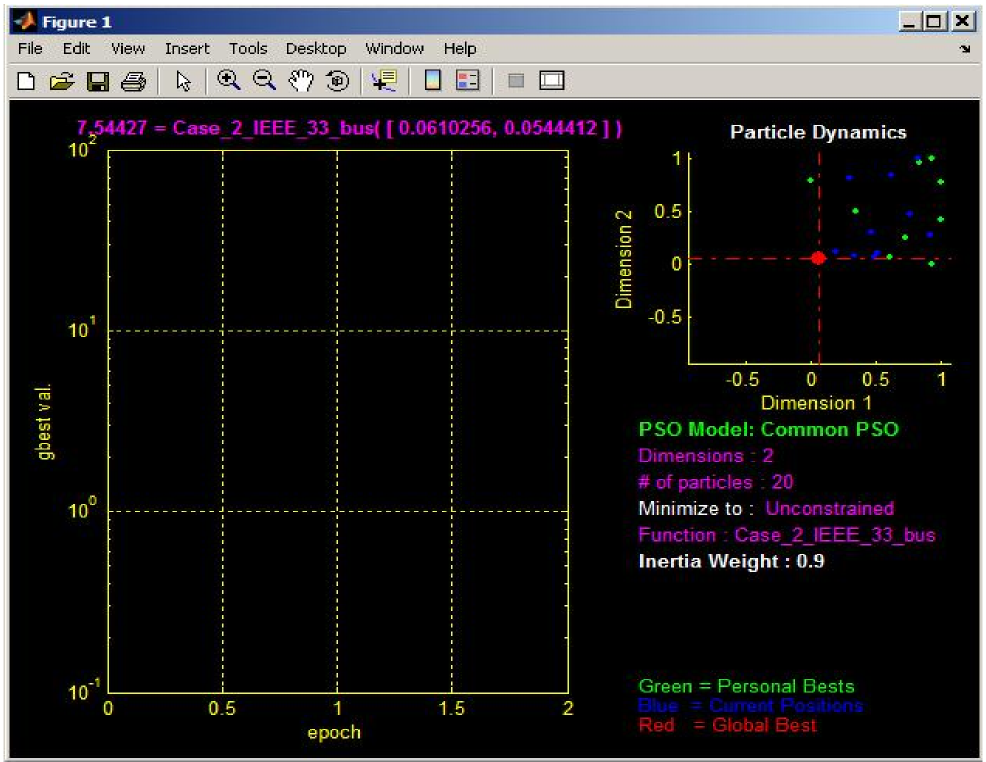

Figure C-7: Searching space for case two at first iteration

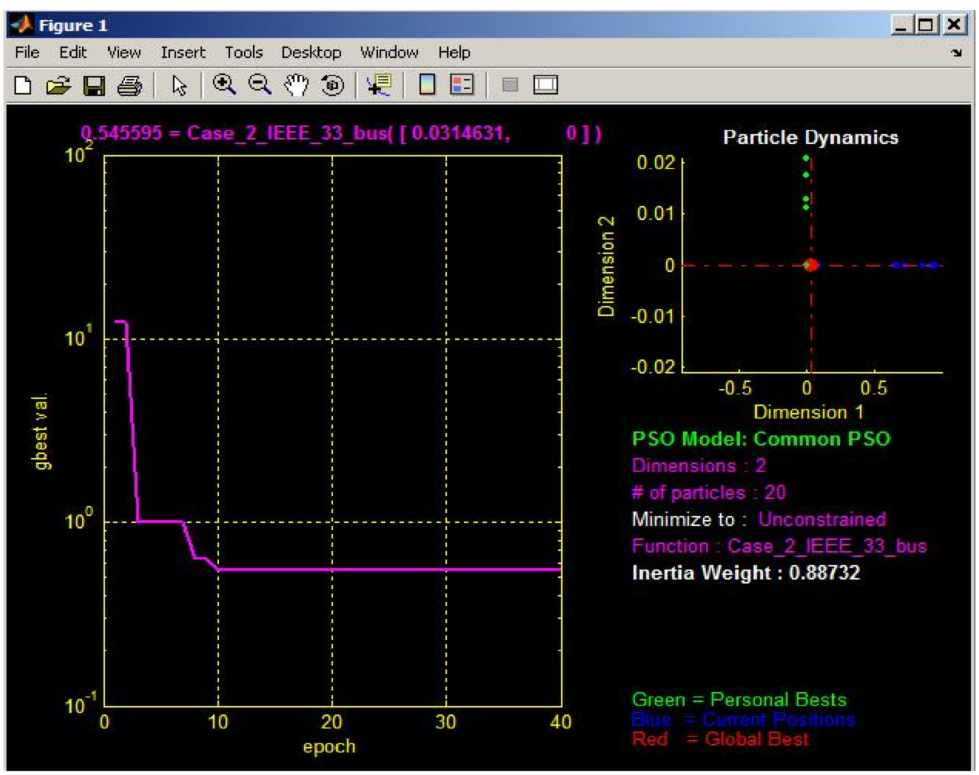

Figure C-8: Searching space for case two in 40 iterations

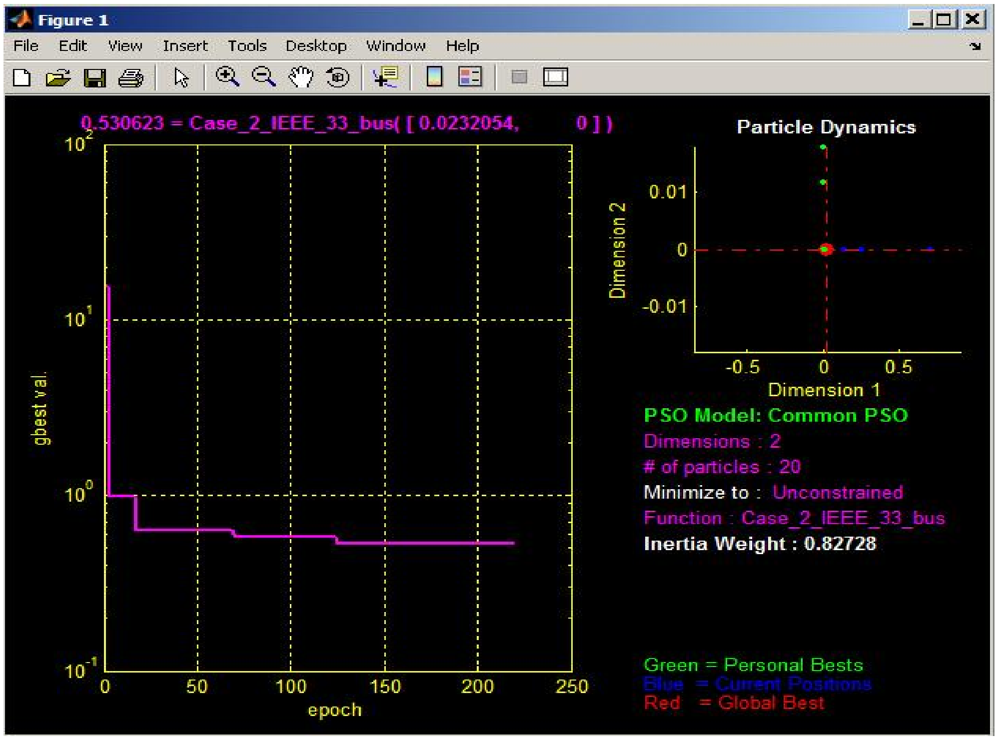

Figure C-9: Searching space for case two after 200 iterations

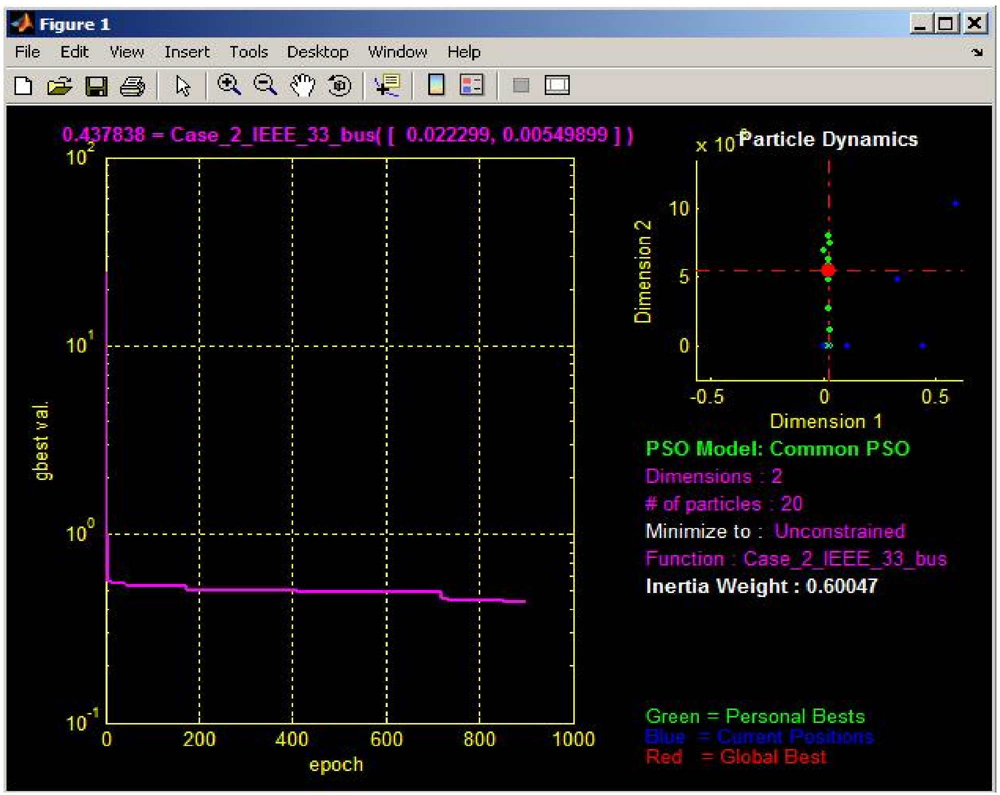

Figure C-10: Searching space for case two after 800 iterations

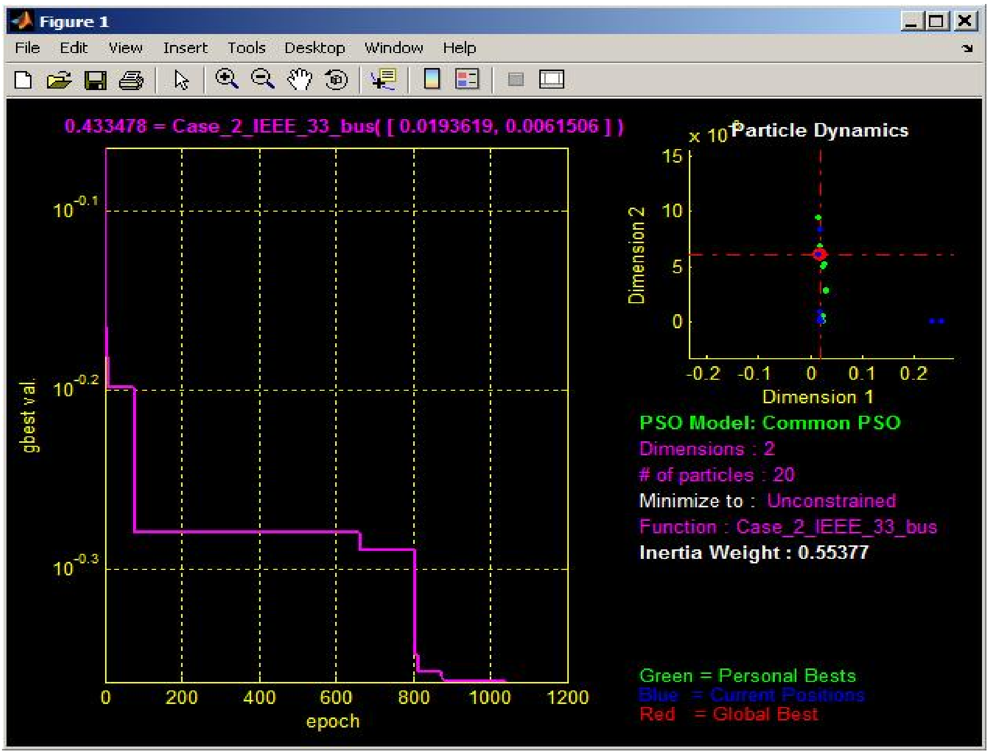

Figure C-11: Searching space for case two in 1000 iterations

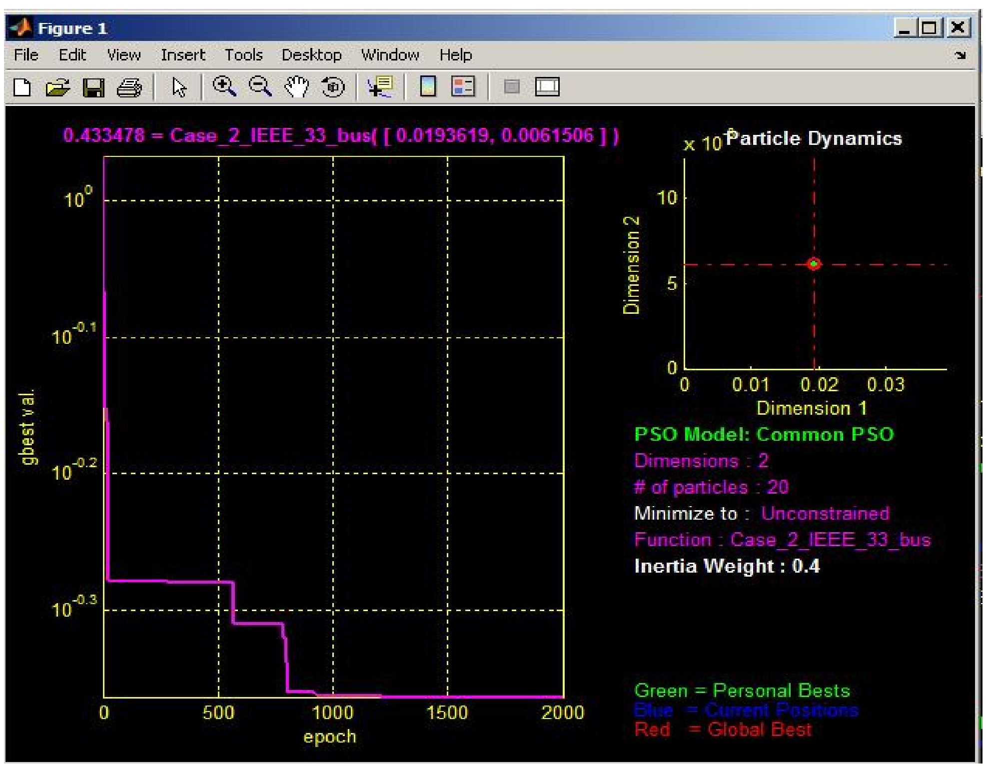

Figure C-12: Searching space for case two in 2000 iterations

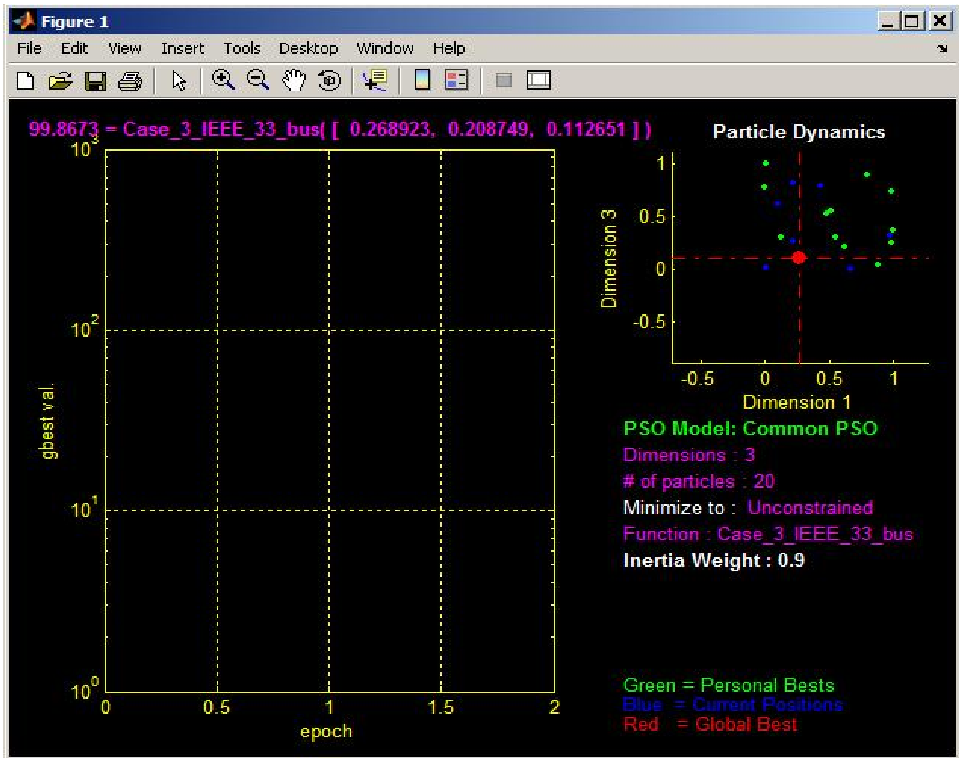

Figure C-13: Searching space for case three at first iteration

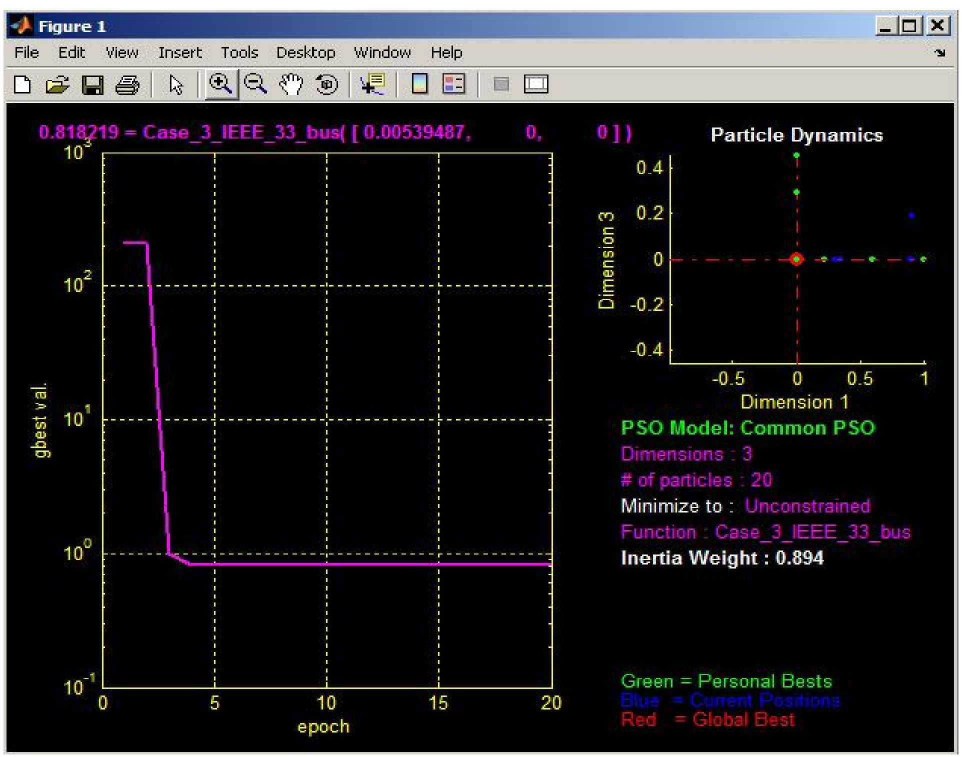

Figure C-14: Searching space for case three in 20 iterations

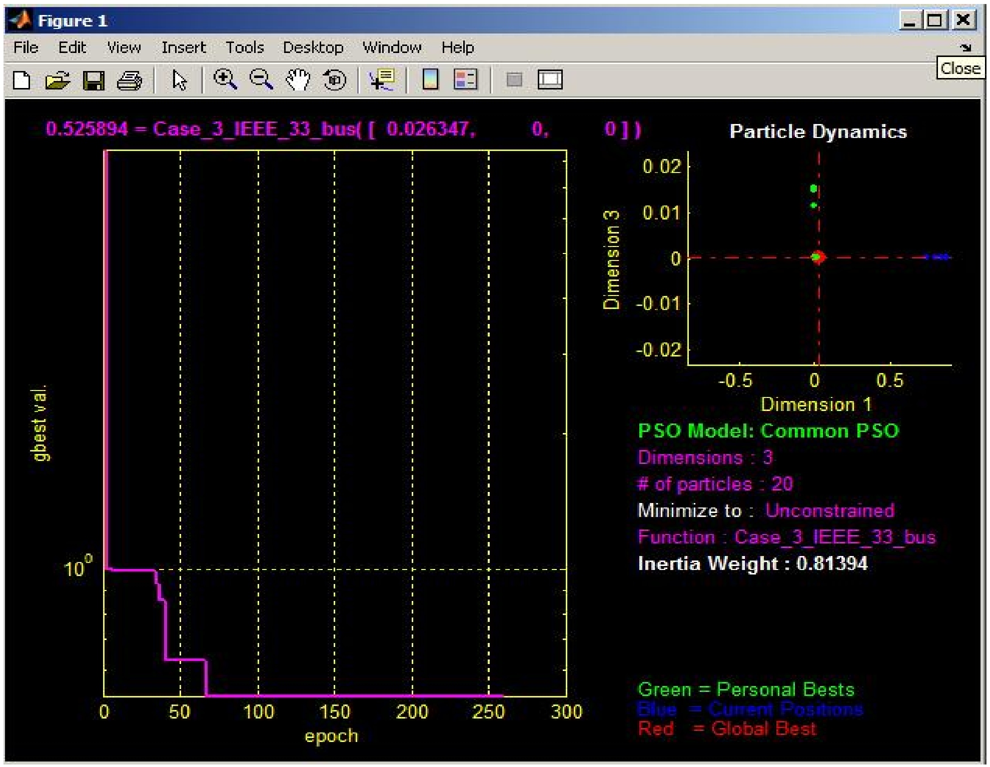

Figure C-15: Searching space for case three in 250 iterations

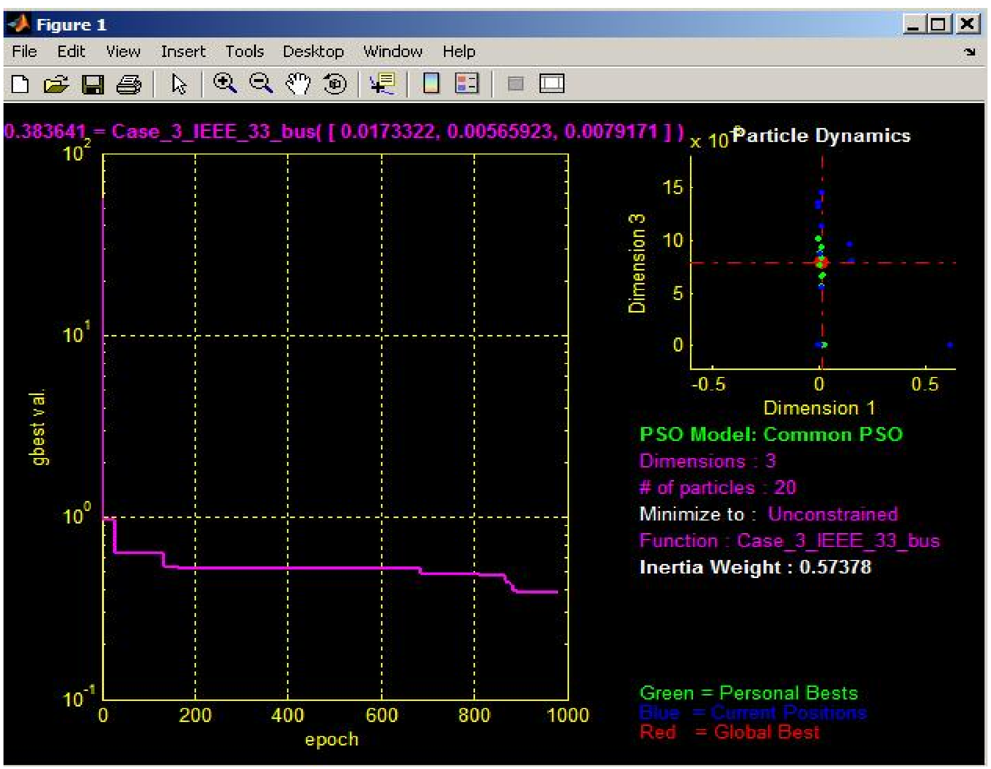

Figure C-16: Searching space for case three in 1000 iterations

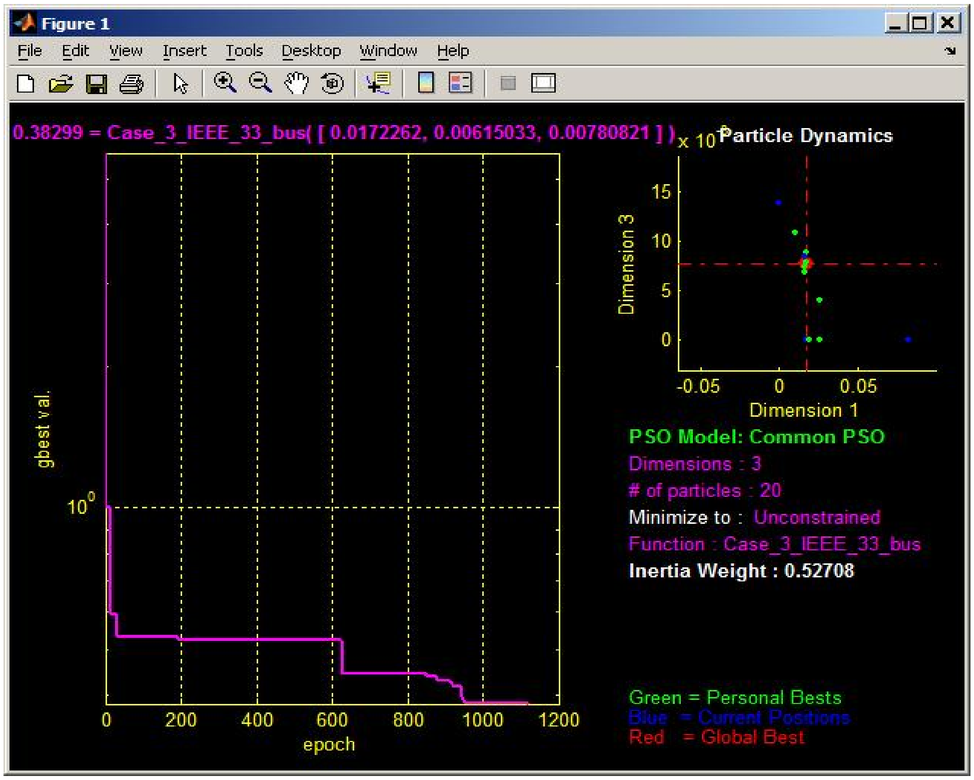

Figure C-17: Searching space for case three in 1200 iterations

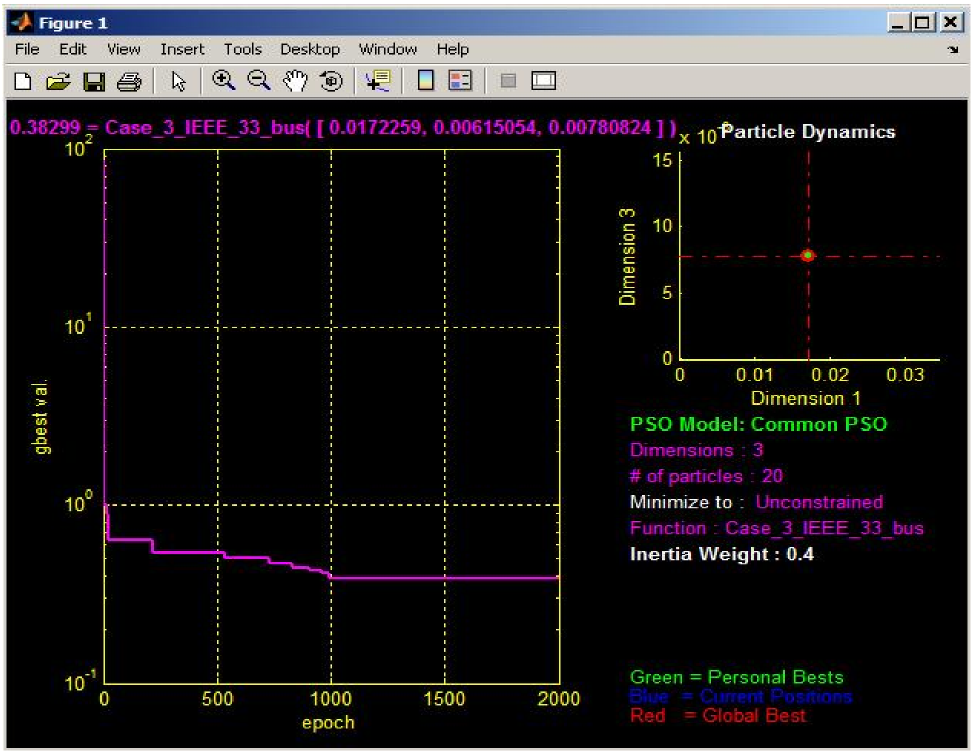

Figure C-18: Searching space for case three in 2000 iterations

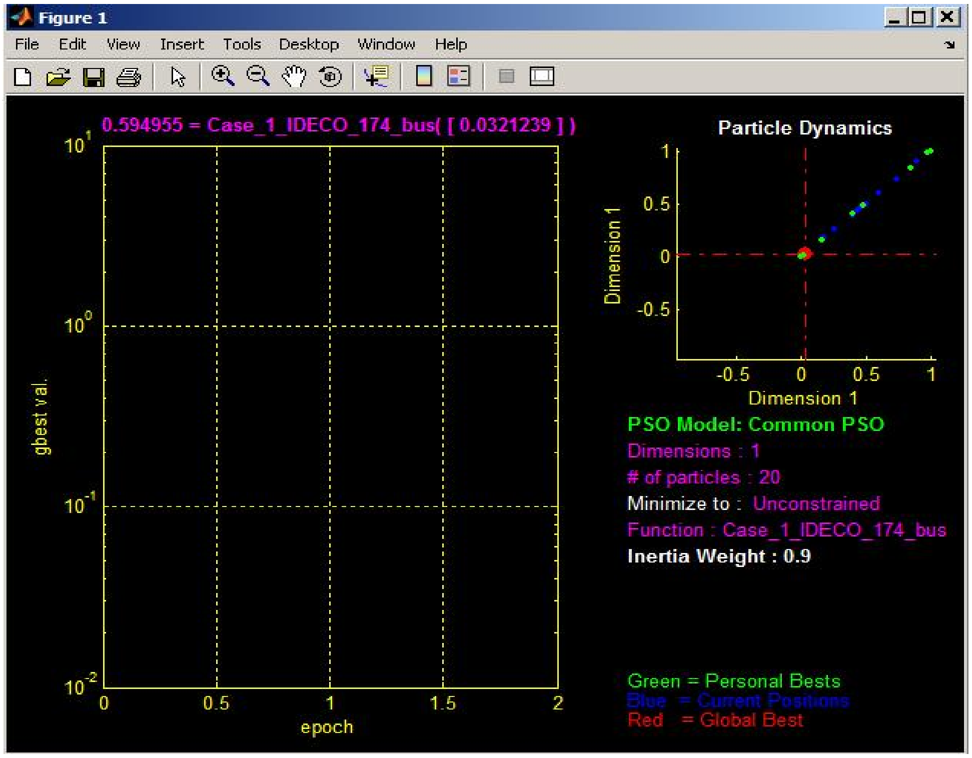

Figure C-19: Searching space for case one of local network at first iteration

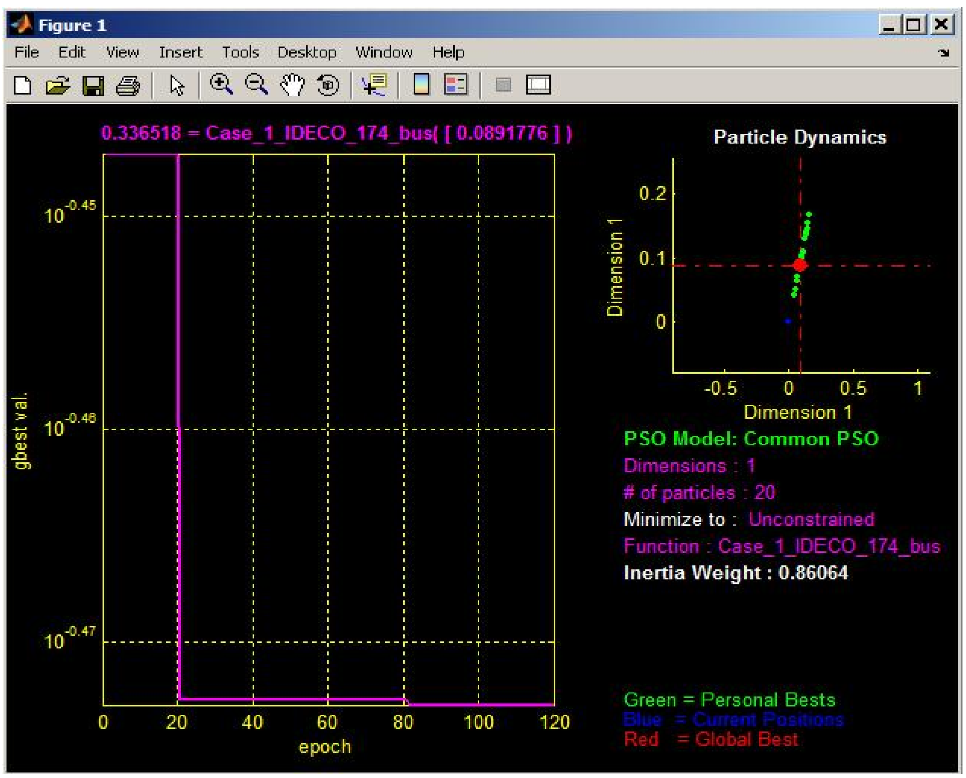

Figure C-20: Searching space for case one of local network in 120 iterations

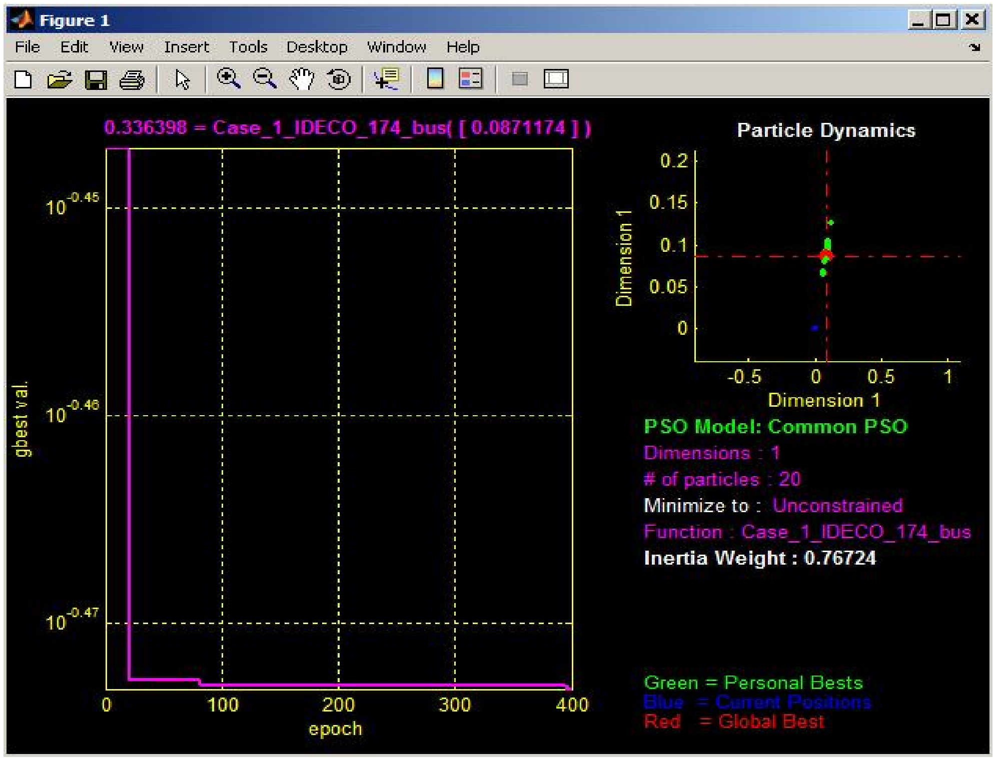

Figure C-21: Searching space for case one of local network in 400 iterations

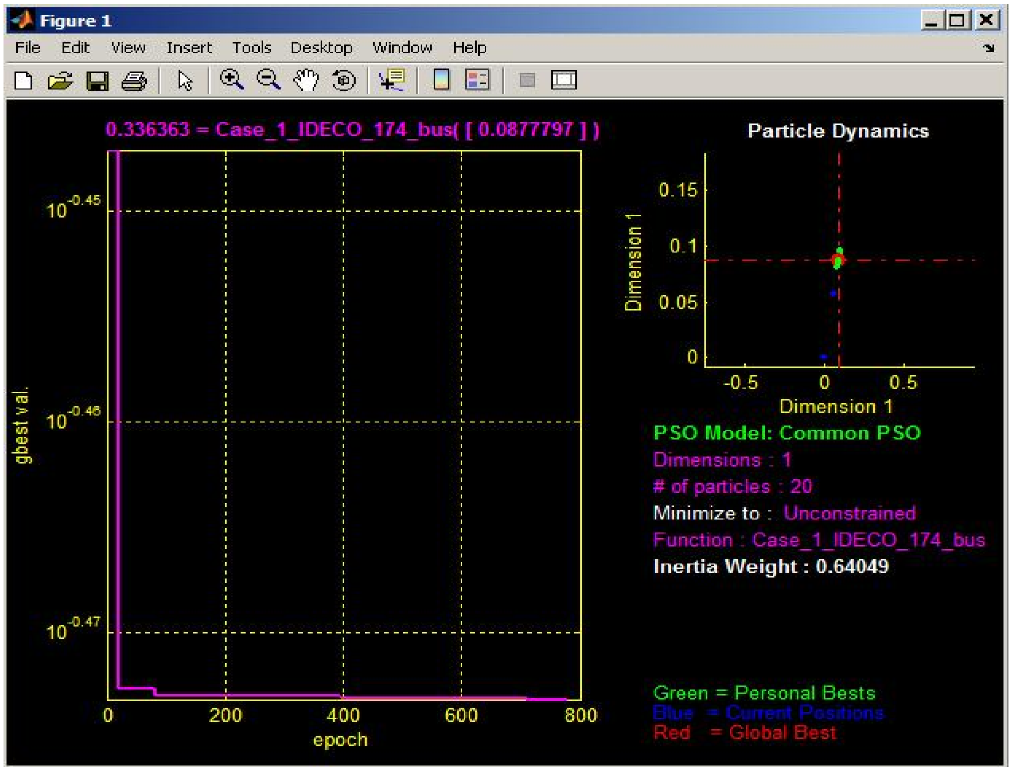

Figure C-22: Searching space for case one of local network in 800 iterations

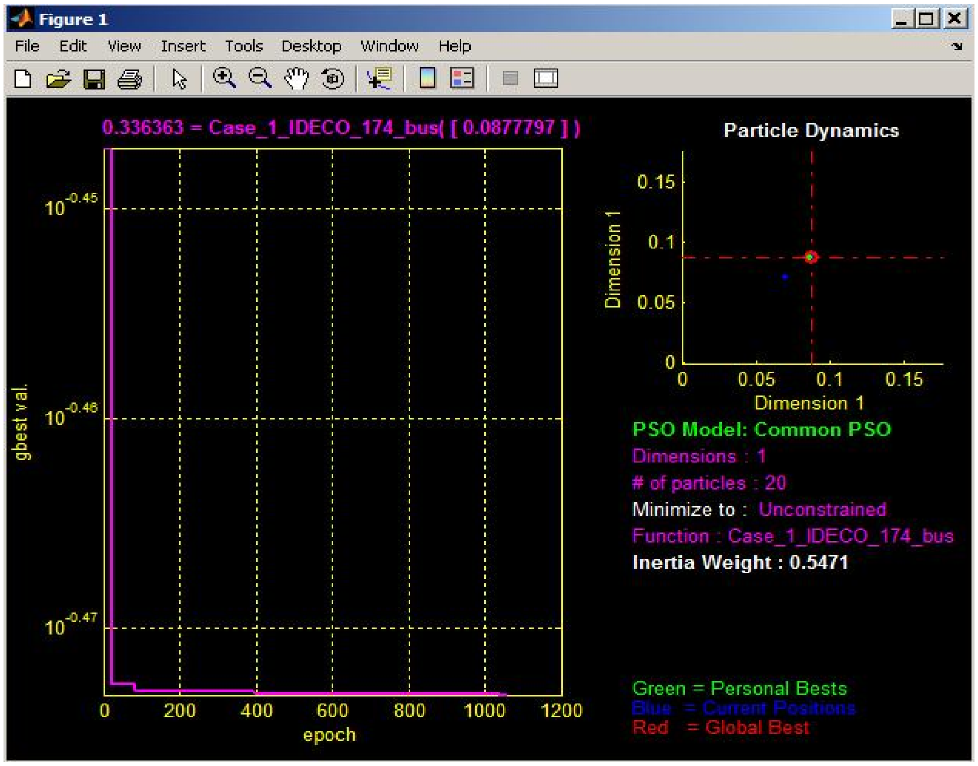

Figure C-23: Searching space for case one of local network in 1000 iterations

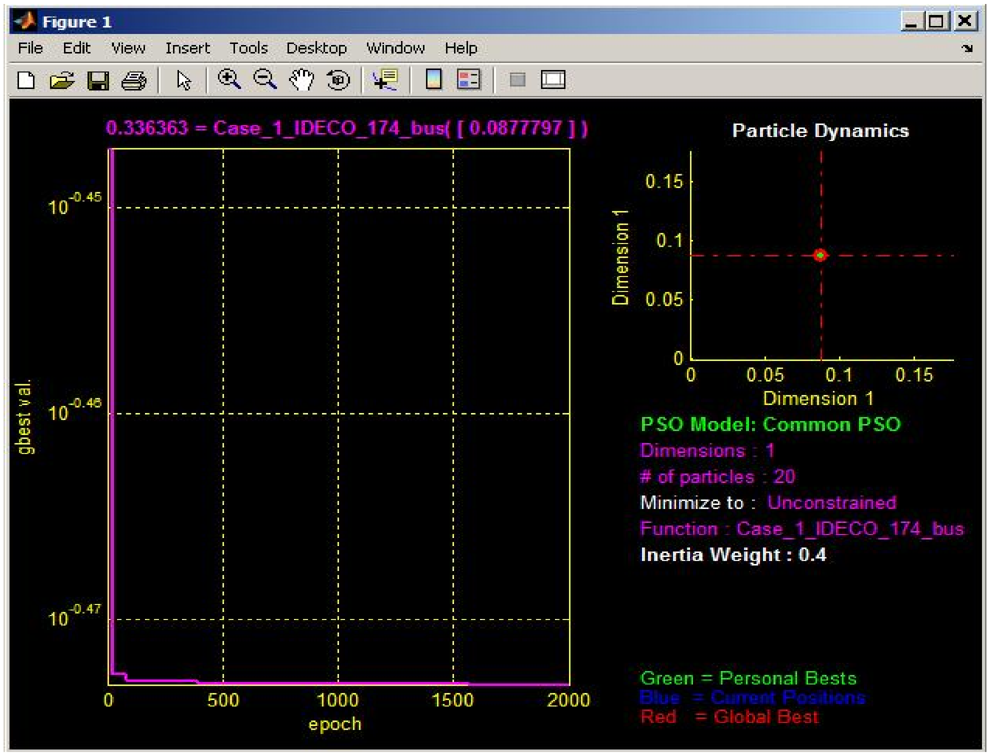

Figure C-24: Searching space for case one of local network in 2000 iterations

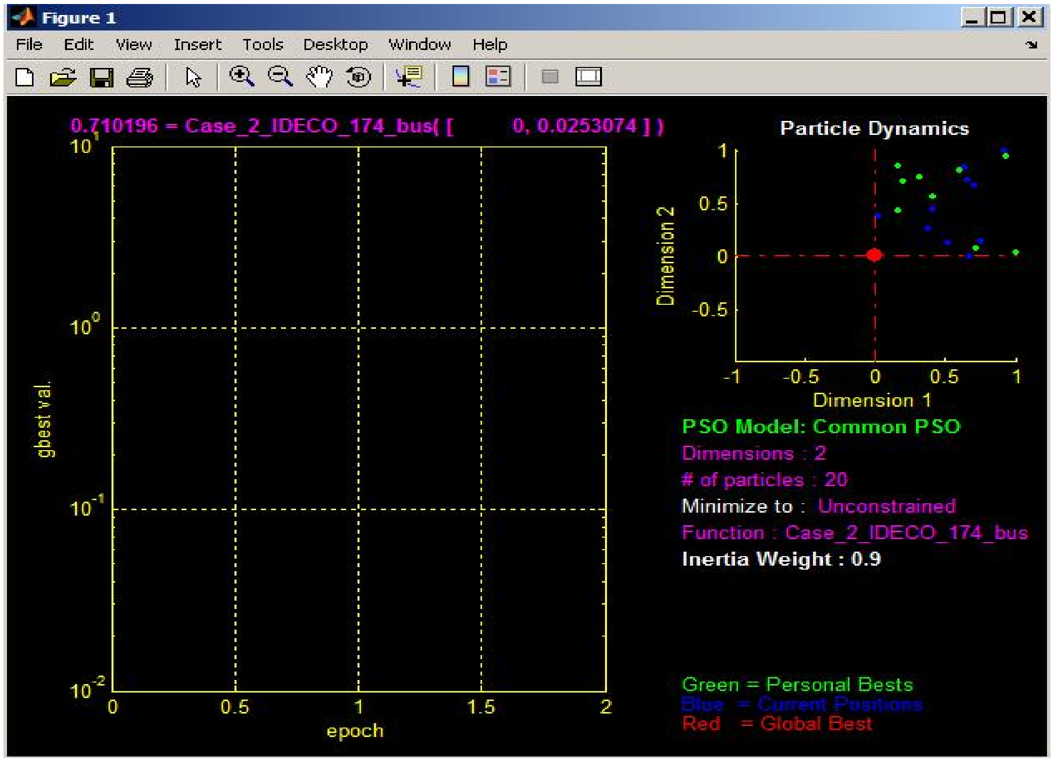

Figure C-25: Searching space for case two of local network at first iteration

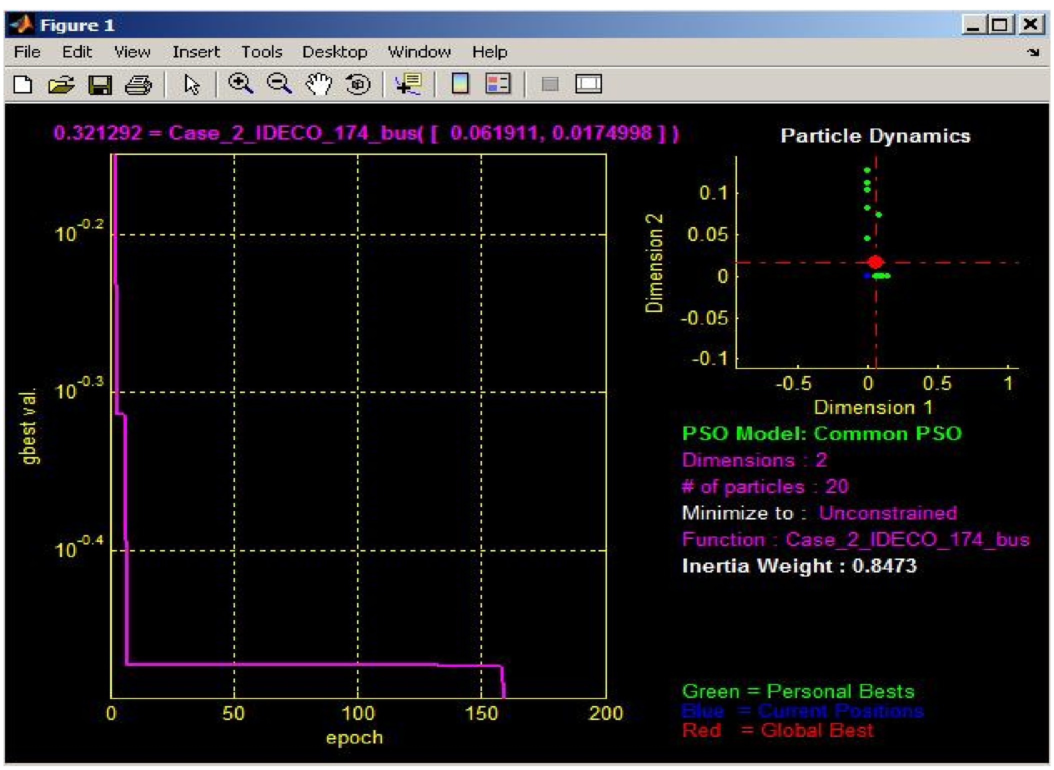

Figure C-26: Searching space for case two of local network in 150 iterations

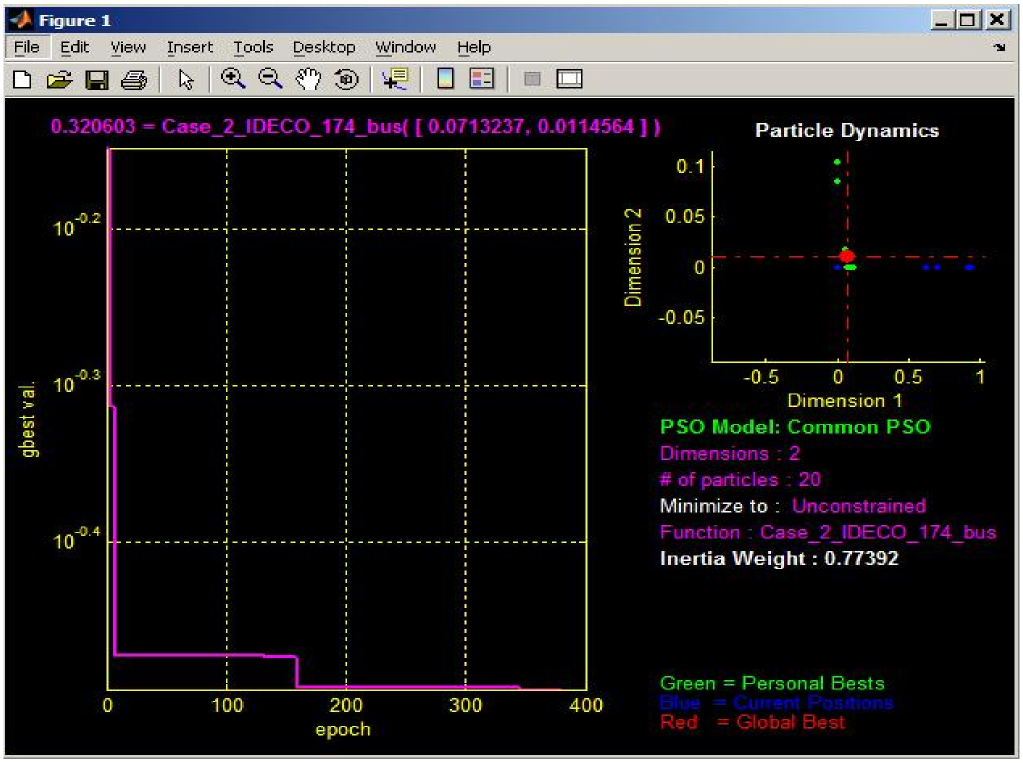

Figure C-27: Searching space for case two of local network in 400 iterations

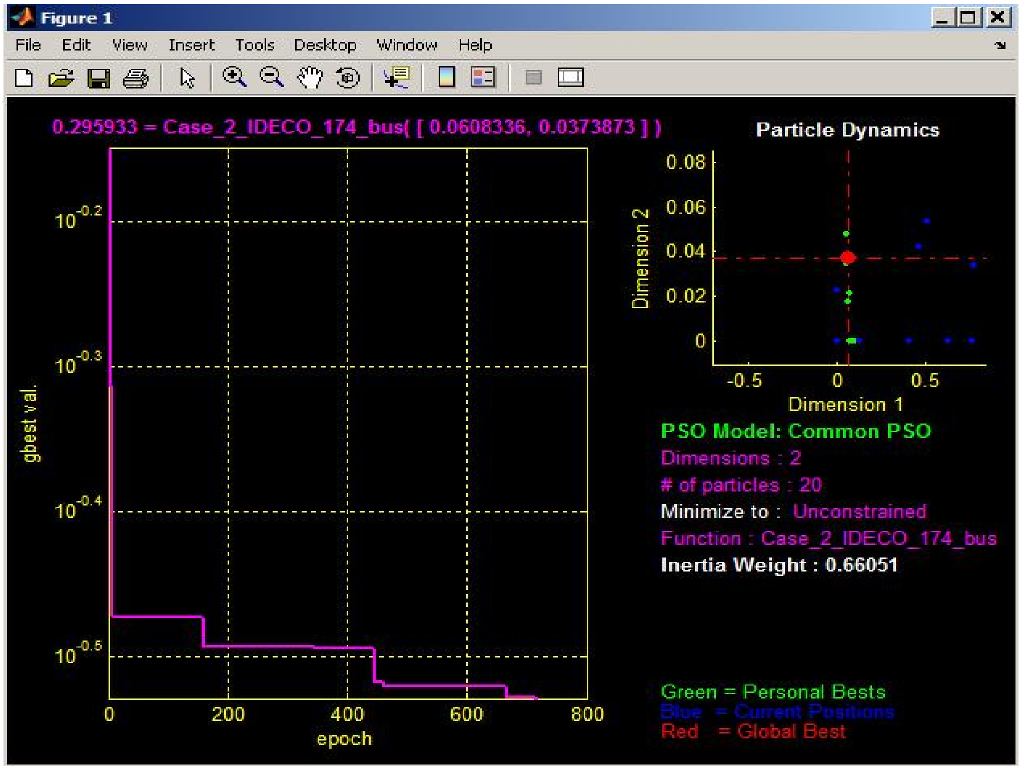

Figure C-28: Searching space for case two of local network after 600 iterations

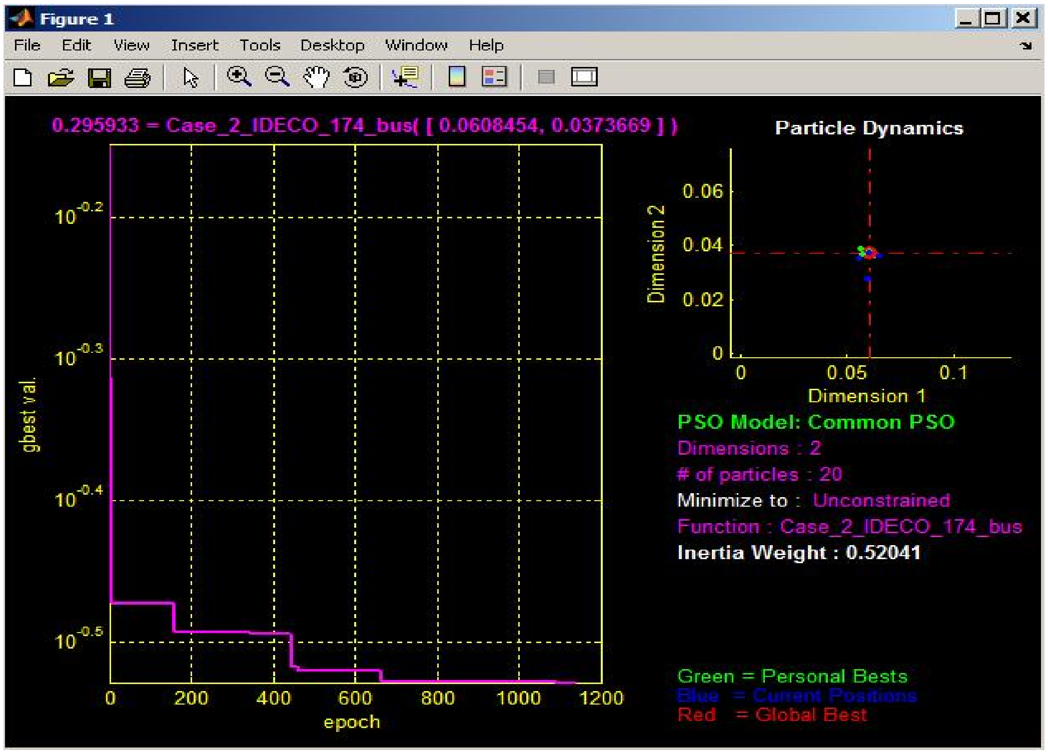

Figure C-29: Searching space for case two of local network after 1000 iterations

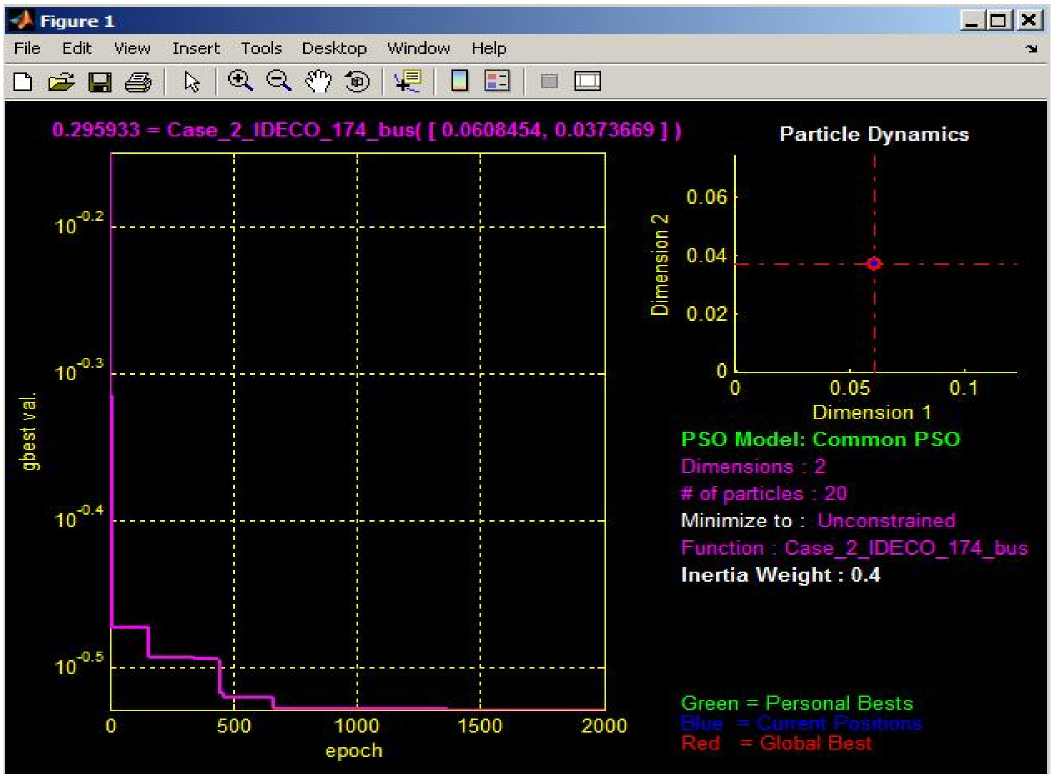

Figure C-30: Searching space for case two of local network in 2000 iterations

تأثير موقع وسعة التوليد الموزّع على تقليل الفقد في نظام التوزيع الكهربائي

إعداد

دريد شطناوي

المشرف

الدكتور سامح الشهابي

ملخص

يعمل نظام التوزيع الكهربائي على ايصال التيار الكهربائي إلى المشتركين بكافاءة وجودة. يتم تصميم شبكات التوزيع الكهربائي عادة بشكل شعاعي، حيث يزداد الفقد الكهربائي في الخطوط وتهبط الفولطية على الباسبارات كلما ابتعدنا أكثر عن مصدر التغذية الرئيسي وذلك نتيجة انخفاض القدرة المنقولة في الخط والتي من الممكن تعويضها باستخدام التوليد الموزّع.

التوليد الموزّع عبارة عن مولدات صغيرة الحجم يتم ربطها بشكل مباشر على شبكات التوزيع الكهربائي بالقرب من المشتركين، وهي تعتبر حديثاً من الحلول الفعالّة في خفض الفقد الكهربائي وتحسين الفولطية، مع الاخذ بعين الإعتبار موقع وسعة التوليد الموزّع للحصول على أفضل النتائج. ولتحقيق هذا الهدف تمّ إقتراح خوارزمية تستخدم معامل حساسية خفض الفقد لإيجاد الموقع الأفضل للتوليد الموزّع ومفاضلية سرب الجزيئات لحساب السعة الأفضل.

تمّ تطبيق الخوارزمية على شبكة توزيع كلاسيكية من جمعية مهندسي الكهرباء والإلكترونيات وشبكة توزيع محلية من شركة كهرباء محافظة إربد، حيث بيّنت النتائج فاعليّة الخوارزميّة المقترحة في تحديد السعة والموقع الأفضل للتوليد الموزّع، كما أوضحت النتائج أنّ استخدام التوليد الموزّع في شبكات التوزيع يعطي نتائج أفضل من استخدام المكثفات لغايات خفض الفقد الكهربائي وتحسين مستوى الفولطية.